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Space Station Integrated Propulsion and Fluid Systems Study

Space Station Program Fluid Management Systems Databook

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Space Station Program
Fluid Management
Systems Databook

SPACE STATION INTEGRATED PROPULSION AND FLUID SYSTEMS STUDY

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FOREWORD

This report was prepared by Martin Marietta Space Systems Company under Contract NAS8-36438 in compliance with the Statement-of-Work. The contract is being administered by Marshall Space Flight Center, Huntsville, Alabama. Mr. John Cramer is the NASA Project Manager.

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List of Acronyms

ACS	Atmosphere Control and Supply
CFES	Continuous Flow Electrophoresis in Space
CIX	Continuous Ion Exchange (Synonym for Electrodeionization)
ECLSS	Environmental Control and Life Support System
EEU	Extra-vehicular Excursion Unit
ELM	Experimental Logistics Module
ESA	European Space Agency
EVA	Extra-vehicular Activity
°F	Degrees Fahrenheit
FDS	Fire Detection and Suppression
FMS	Fluid Management System
FTIR	Fourier Transform Infrared (Spectrometer)
HFM	Hollow Fiber Membrane
HSD	Hamilton Standard Division of United Technologies
IFMS	Integrated Fluid Management System
IOC	Initial Operational Capability
INS	Integrated Nitrogen System
IR&D	Independent Research and Development
ITCS	Internal Thermal Control System
IVA	Intra-vehicular Activity
IWFS	Integrated Waste Fluid System
IWS	Integrated Water System
JEM	Japanese Experimental Module
KOH	Potassium Hydroxide
LHe	Liquid Helium
MDAC	McDonnell Douglas Astronautics Company
MEOP	Maximum Expected Operating Pressure
MF	Multifiltration
MLI	Multi-Layer Insulation
MMU	Manned Maneuvering Unit
MSFC	(George C.) Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NSTS	National Space Transportation System
OMV	Orbital Maneuvering Vehicle
OTV	Orbital Transfer Vehicle
PLC	Pressurized Logistics Carrier
PMMS	Process Materials Management System
PPV	Portable Pressure Vessel
PWHS	Process Waste Handling System
QD	Quick Disconnect
RMS	Remote Manipulator System
SEM	Scanning Electron Microscope
SIRTF	Space Infrared Telescope Facility
SS	Space Station
SSP	Space Station Program
TCS	Thermal Control System
TED	Thermoelectric Device
ULC	Unpressurized Logistics Carrier
USL	United States Laboratory
UV	Ultraviolet
WM	Waste Management
WQM	Water Quality Monitor

1.0 INTRODUCTION

Martin Marietta Astronautics Group is currently performing a study to provide NASA Marshall Space Flight Center with an evaluation of commonality and integration of propulsion and fluid systems associated with the Space Station elements. The Space Station elements consist of the core station, which includes habitation and laboratory modules, nodes, airlocks, and trusswork; and associated vehicles, platforms, experiments, and payloads.

The program is being performed as two discrete tasks. Task I investigated the components of the Space Station architecture to determine the feasability and practicality of commonality and integration among the various propulsion elements. This task has been completed. Task II is examining integration and commonality among fluid systems which were identified by the Phase B Space Station contractors as being part of the initial operating capability (IOC) and growth Space Station architectures.

Requirements and descriptions for reference fluid systems have been compiled from Space Station documentation and other sources. The fluid systems being examined are: an experiment gas supply system, an oxygen/hydrogen supply system, the integrated water system, the integrated nitrogen system, and the integrated waste fluids system. Definitions and descriptions of alternate systems have been developed, along with analyses and discussions of their benefits and detriments. This databook includes fluid system descriptions, requirements, schematic diagrams, component lists, and discussions of the fluid sytems. In addition, cost comparisons are used in some cases to determine the optmum system for a specific task.

2.0 FLUID SYSTEM COMMONALITY ASSESSMENT

Two seperate assessments of fluid system commonality were performed over the duration of this study. The first was performed under Task I and was incorporated into EP 2.3, the "Space Station Program Fluid Systems Hardware Catalog." This original assessment examined hardware commonality among propulsion systems by comparing hardware which had been defined in Space Station Program documentation and had been included in the Space Station fluid system component database. Components which were indicated for use in more than one propulsion system were listed as common hardware. Initial efforts on the Integrated Fluid System Definition indicated a need for a more extensive commonality study. The realization that many fluid systems had not been defined to the component level provided an opportunity to design toward a goal of maximum commonality. This reexamination of fluid,system hardware commonality as a design driver instead of just a result has been completed and is presented later in this section. In addition to hardware commonality among fluid systems there is also a need to identify those systems which share common requirements. The following analysis was performed prior to system definition to determine where system integration was appropriate.

2.1 FLUID SYSTEM REQUIREMENTS COMMONALITY

Commonality of requirements for fluid systems was examined using two preliminary selection criteria. Fliuds which were shown to have more than one user were identified as integration candidates, as were byproduct fluids which have potential either for recycling for further use within the Space Station as a non-waste fluid or for use in the integrated waste fluids system. The fluids chosen as possibly benefitting from integration as fluid systems, based on the preliminary selection criteria, are presented in Table 2.1-1. Table 2.1-2 shows byproduct fluids that have potential for use in the integrated waste fluids system.

Table 2.1-1 Candidates for Development as Integrated Fluid Systems

Air	Hydrogen
Argon	Nitrogen
Carbon dioxide	Oxygen
Cleaning Solution	Waste Fluids
Freon	Water
Helium	

Table 2.1-2 Candidates for Disposal to the Integrated Waste Fluids System

Acetylene	Gaseous Helium
Air	Gaseous Nitrogen
Alcohol	Gaseous Oxygen
Argon	Methane
Buffer Solution	Nutrients
Carbon Dioxide	Propane
Cleaning Solution	Solvents
Carbon dioxide/Methane	Stains
Culture Media	Sterilizers
Cutting Polish	Water
Fuels	Xenon
Gaseous Hydrogen	Xylene

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2.2 FLUID SYSTEMS HARDWARE COMMONALITY

The issue of hardware commonality among fluid systems affects both the design of the fluid systems and the cost of building them. Designing several hardware systems to incorporate a great deal of hardware commonality may prevent each system from being built with its *individual* optimum design. An analysis must be performed to determine the best possible mix of design optimization and commonality optimization, which is the *common* optimum design for the several systems. This design should provide the lowest cost system which meets all the requirements of the systems. The following example shows the relationship between the individual optimum design and the common optimum design.

The optimum design of an argon gas delivery system is shown in Figure 2.2-1, and includes two 1 ft^3 storage tanks, each pressurized to 3000 psia. Figure 2.2-2 also shows a gas delivery system, this one for krypton gas. The optimum krypton system requires one 1 ft^3 storage tank pressurized to 2000 psia. Both of these tanks must be independently designed, developed and tested, incurring a great deal of initial cost for each. A much cheaper solution uses only one tank design, building three of the 1 ft^3, 3000 psia tanks, or four of the 1 ft^3, 2000 psia tanks to meet the needs of both storage systems. This combination replaces two individual optimum designs with one common optimum design.

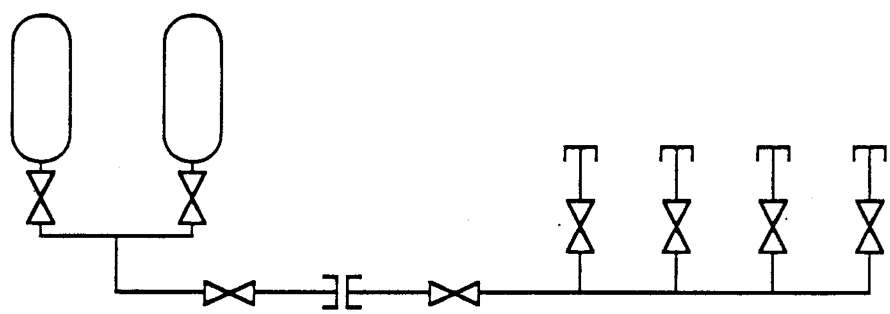

Figure 2.2-1 Example of an Argon Gas Delivery System

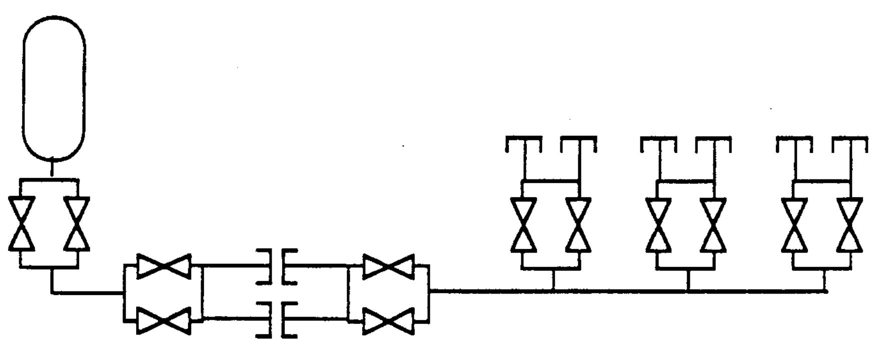

Figure 2.2-2 Example of a Krypton Gas Delivery System

Five levels of component commonality have been identified:

1) No Hardware Commonality, where an individual system shares no hardware with other systems;
2) Partial component Commonality, where some components are also used in other fluid systems, but not in identical sub assemblies;
3) Total Component Commonality, where all components are also used in other fluid subsystems, but not as identical subassemblies;

4) Partial System Commonality, where identical subassemblies are used in other systems; and,
5) Total System Commonality, where identical hardware systems are installed for other fluids also.

Examples of groups of systems which demonstrate these five levels of commonality are shown in Figure 2.2-3. When these five levels of hardware commonality are applied to multiple fluid systems, it quickly becomes apparent that there are several combinations of the five levels. The following example expands on the one presented previously.

A xenon delivery system is required along with the argon and krypton systems identified previously and is being considered as a commonality candidate. The storage and delivery requirements are essentially the same as those for the krypton system, which will allow the use of the identical design for both systems. Ranking these three systems together with the scale listed above give the following results.

Xenon ranks:
- 5 with krypton
- 2 with argon

Krypton ranks:
- 5 with xenon
- 2 with argon

Argon ranks:
- 2 with xenon
- 2 with krypton

Further analysis shows that there are many possible combinations when a large number of systems are mutually ranked. The total number of possible combinations is sixteen, ranked 0 to 15, which are shown below:

15)	5
14)	5,4
13)	5,4,3
12)	5,4,3,2
11)	5,4,2
10)	5,3
9)	5,3,2
8)	5,2
7)	4
6)	4,3
5)	4,3,2
4)	4,2
3)	3
2)	3,2
1)	2
0)	1

Although this list is more complete and includes all the possible levels of commonality, it is quite confusing and does not directly point out those systems into which a high level of commonality has been designed. A third list of commonality rankings was generated which includes combinations of levels where they are appropriate, but also limits the analysis to the highest commonality level which a given system might have with any of the other systems.

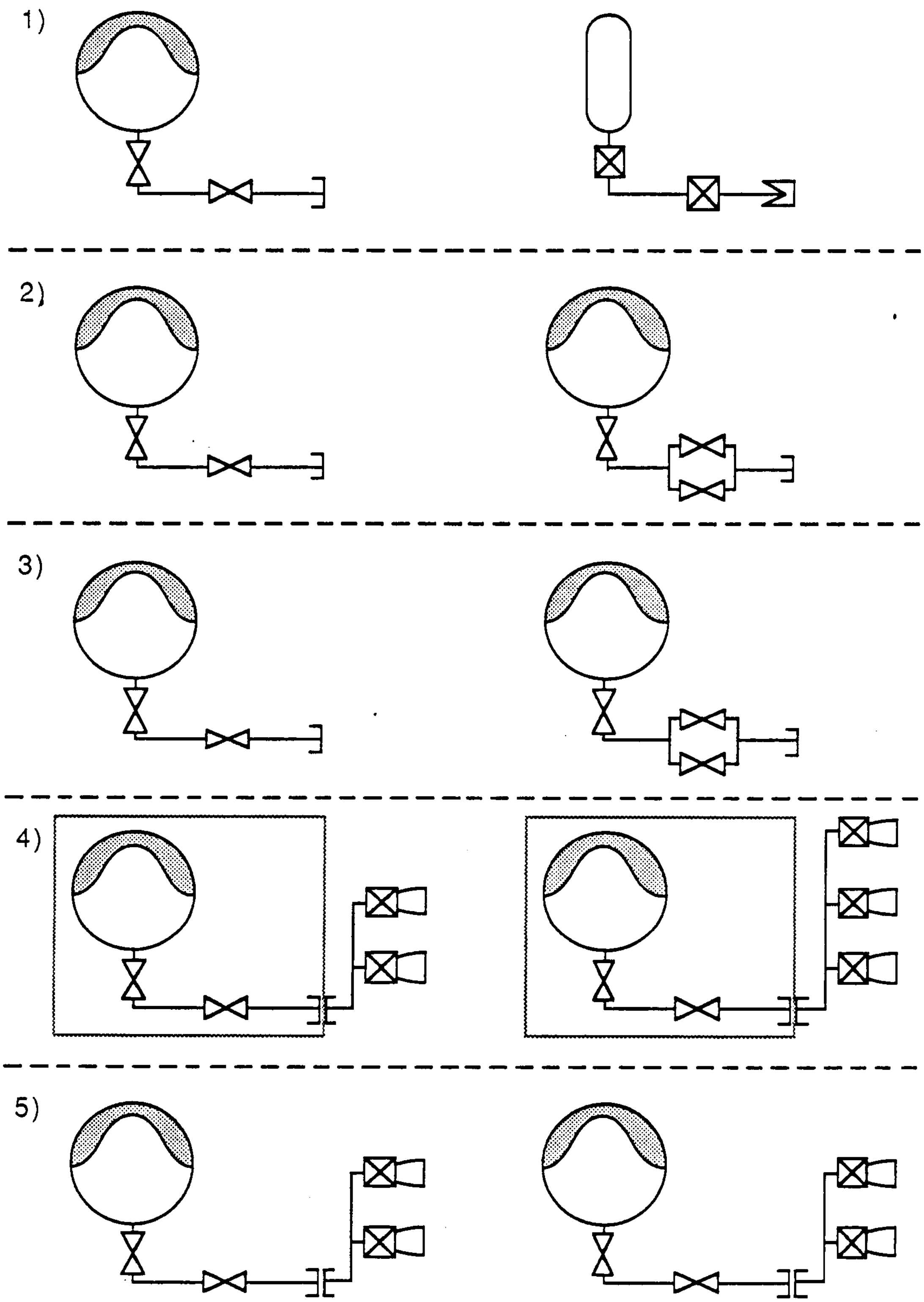

Figure 2.2-3 The Five Primary Commonality Levels

There are seven levels of commonality in this system, ranked 0 to 6, which are listed below:

6) 5 Identical duplicate systems are used with at least one other fluid.
5) 4 All subasemblies are used with at least one other fluid.
4) 4,3 Some subassemblies are used with at least one other fluid, and the remaining components are also used with at least one other fluid.
3) 4,2 Some subassemblies are used with at least one other fluid, and some of the remaining components are also used with at least one other fluid.
2) 3 All the individual components are also used in other fluid systems, but not as identical subassemblies.
1) 2 Some of the individual components are also used in other fluid systems, but not as identical subassemblies.
0) 1 No hardware commonality.

The each gas listed in Table 2.2-1 was analyzed to determine the level of commonality it shares with each of the others to determine its maximum commonality ranking. Included in Table 2.2-1 are the commonality ranking assigned to each gas, and the gas(es) with which the ranked gas achieved that ranking. Table 2.2-2 shows the same information for the liquids in the study.

Table 2.2-1 Commonality Among Gases

Gas	Quantity	Volume*	Ranking	Common Systems
Ar	170.0	5.5	6	H_2, NH_3
Cl_2	8.8	6.6	5	Ar, NH_3,H_2
CO_2	38.1	4.8	5	Ar, Kr
CO_2/CH_4	958.0	-	2	CO_2
C_2H_2 (Acetylene)**	-	-	0	N/A
C_3H_8 (Propane)	6.6	0.9	6	Xe, Kr, SiH_4
C_4H_{10} (Butane)	-	-	-	-
H_2	1.7	5.0	6	Ar, NH_3
He	9.8	14.3	6	N_2
Kr	9.9	0.6	6	Xe, C_3H_8, SiH_4
N_2	77.0	15.5	6	He
NH_3 (Ammonia)	2.2	5.5	6	Ar, H_2
O_2	207.3	35.4	5	N_2, He
SiH_4 (Silane)	6.6	0.6	6	Kr, Xe, C_3H_8
Xe	16.0	0.2	6	Kr, C_3H_8,SiH_4

* Volumes are at 1000 psia and 70°F except Cl_2 @ 95 psia, Ammonia @ 120°F, Butane @ 30 psia and Propane @ 120 psia to avoid liquefaction.

** Acetylene must be stored in special tanks. No commonality is possible.

Table 2.2-2 Commonality Among Liquids

Liquid	Quantity	Ranking	Common Systems
Alcohol	TBD	2	Cleaning Solution
Cleaning Solution	TBD	2	Alcohol
Freon	TBD	TBD	
HCl	TBD	2	Toluene, Xylene
He	TBD	1	N_2
N_2	TBD	1	He
Toluene	TBD	2	HCl, Xylene
Water	TBD	0	N/A
Xylene	TBD	2	HCl, Toluene
Other *	TBD		

* Other includes buffer solution, culture media, cutting polish, echants, nutrients, solvents, stains, and sterilizers.

3.0 INTEGRATED EXPERIMENT GAS SUPPLY AND DISTRIBUTION SYSTEMS

The fluid systems for which integration was investigated included several experiment gases. The supply and distribution systems of argon, carbon dioxide, helium, and experiment air were examined to determine the possible benefits of uniting the many individual gas supplies ncessary into four systems, one for each gas. In addition, the possible use of similar designs for each of these systems was studied.

3.1 EXPERIMENT GAS USAGE

Argon is used in the USL, JEM, and Columbus laboratories on the Space Station, and in at least one of the attached payloads. Because of the large quantities of argon required, about 316 lbm per 90 days, the argon supply system looks to be a good candidate for integration. Of this 316 lbm, 80 lbm is used by the attached payloads. The remaining 236 lbm is divided among the three laboratories.

Carbon dioxide is used in the USL, JEM, and Columbus laboratories on the Space Station. Because of the quantities of carbon dioxide required, about 63 lbm per 90 days, the carbon dioxide supply system also looks to be a good candidate for integration. Also of note is the fact that the Environmental Control and Life Support System (ECLSS) produces carbon dioxide as a by-product of its air revitalization process.

Helium is used in the USL, JEM, and Columbus laboratories on the Space Station and in at least one of the attached payloads. The use of helium by the Space Station experimental modules is very minimal, about 8.5 lbm per 90 days which occupies a storage volume of 1 cubic foot or less at the proposed storage pressures of 2000 to 3000 psia. The 8.5 lbm is comprised of 4.4 lbm for the USL Module, 1.9 lbm for the JEM Module and 2.2 lbm for the Columbus Module. At least one of the attached payload experiments uses a large amount of helium, 180.4 lbm, which is supplied in a superfluid helium dewar. A portion of the gaseous helium effluent from the attached payloads may be used in the experimental modules. The small quantities of helium required limit the practicality of integrating helium supply and distribution systems into one integrated system.

Air is used for two functions on the Space Station: cabin air and experiment air. Cabin air makes up the breathable living environment for the crew. This air contains water, carbon dioxide and other contaminants besides the primary constituents, oxygen and nitrogen. Cabin air will vary in composition depending on crew size, airlock useage, and cabin leakage. The partial pressure of oxygen and the total cabin pressure are monitored and maintained by adding oxygen and nitrogen individually as required. Carbon dioxide and other contaminants are removed from the cabin air by the Space Station's Environmental Control and Life Support System.

Dry, contaminant-free air is required by experiments in all three laboratories. This air is used for respiration, purging, and as a reagent. Total and partial pressure requirements of the air and its constituents are not available for these experiments. If there is any variation in the properties of the air required, the air must be made up from its constituents, oxygen and nitrogen, in the proper mixture to meet the requirements. This mixing is performed by the individual experiments. This mixing requirement, along with the fact that both nitrogen and oxygen are already supplied throughout the Space Station modules, eliminates the need for an integrated air system.

In the case that air need be supplied as a common gas, the supply and distribution systems would be similar to those of the experiment gas supply system. Refer to the integrated experiment gas supply system definition for a discussion of the apparatus.

3.2 INTEGRATED EXPERIMENT GAS SUPPLY SYSTEMS

The following are descriptions of possible experiment gas system configurations. Two different parts of the overall systems are discussed. The supply system configurations provide the means for bringing the gases to the Space Station on the NSTS Shuttle and supplying them to common locations. The distribution systems take the gases from the supply systems and distribute them to the locations where they are required, such as in an experiment rack. The optimum experiment gas system for each gas will be derived by combining one of the supply systems with one of the distribution systems, and may include the benefits realized from the use of similar systems for more than one gas. The selection of the most appropriate overall system for Space Station will be made after considering cost impacts and other factors such as operational flexibility, safety, reliability, and maintenance.

3.2.1 Baseline Supply and Distribution Configurations

Space Station Program documents call out only one means for the supply of experiment gases to their various users, a process fluids rack with numerous pressure vessels for the supply of the required process gases. The gases are delivered to their users by manually removing the pressure vessels from the fluids rack and installaing them in the experiment racks. Figure 3.2-1 shows a design concept for the fluids rack. No further description of this system is provided. Figure 3.2-2 shows a Space Station module layout and how the fluids rack is located in it. The use of portable pressure vessels provides a great deal of flexibility; however, it also makes transportation (launch) costs high by decreasing the usable mass fraction. Resupply using a fluids rack eliminates the need to return unused gases to earth on board the Logistics Module when they are not used on schedule.

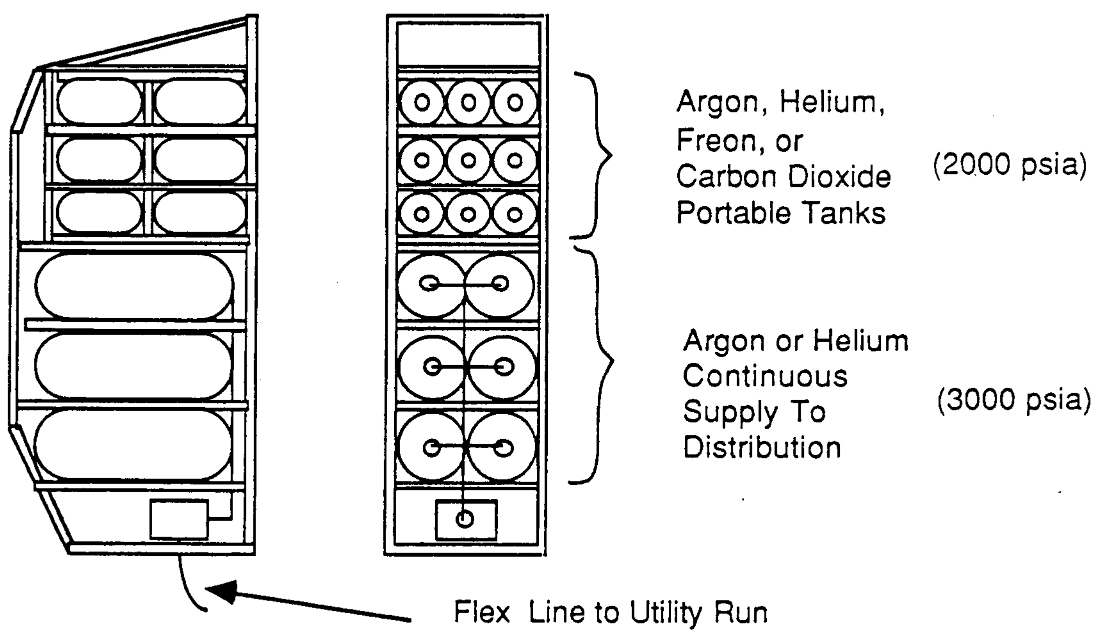

Figure 3.2-1 Fluids Rack Design Concept

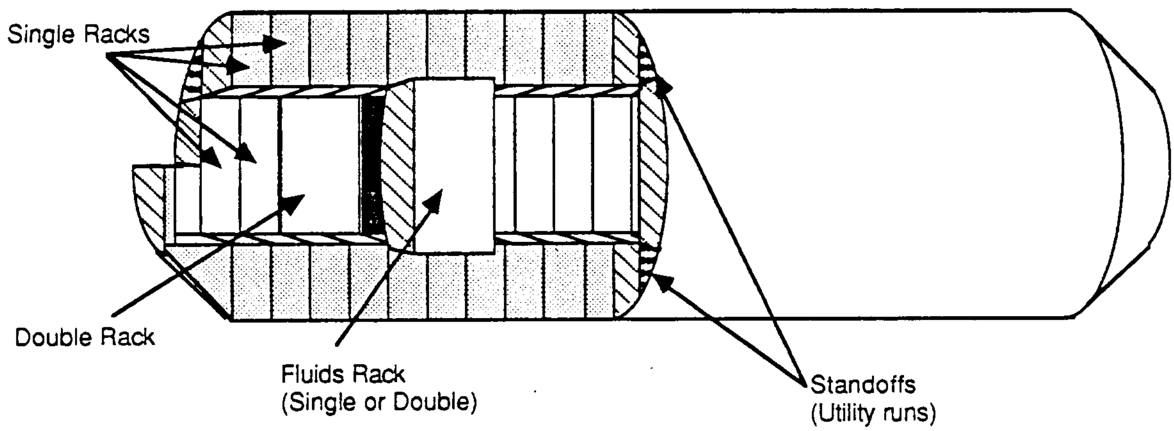

Figure 3.2-2 Location of Fluids Rack in Space Station Module

3.2.2 Supply Configurations for Integrated Systems

There are several methods of supplying the experiment gases in addition to the baseline method discussed previously. Carbon dioxide, helium, and argon can all be brought to the Space Station as liquids or gases, and carbon dioxide can also be transported as a solid. The liquid and solid forms of these chemicals have higher densities than the gas forms, but they present storage and distribution problems that make them more difficult to deliver to their users.

Gases can be supplied to the Space Station at moderate pressures (1000-3000 psia) at ambient temperature (70°F). As explained previously, the baseline gas systems supply the gases to their users in small individual pressure tanks, some of which are used for batch resupply. These gases are better supplied, however, by delivering one or two large pressure tanks of each gas to the Space Station, and subsequently distributing the gases to their users. Fluid conditioning is not required to drive the gases from the storage vessels to the distribution systems. These tanks can be delivered on fluids pallets on the Unpressurized Logistics Carrier or in a fluids rack within the Pressurized Logistics Carrier.

Liquids or supercritical cryogens, as in the case of helium, can be supplied to the Space Station more efficiently than gases because their densities are greater. Distribution of these fluids is not as simple as distribution of gases. Fluid conditioning is required to convert them to gases for use in the experiments. Storing the fluids in these condensed states requires moderate to high pressures and low temperatures, as well as some type of cooling mechanism for temperature maintenance. The following descriptions make no distinction as to whether the fluids arrive at the station as gases, liquids, or supercritical cryogens; they do assume the fluids being transferred to the distribution systems are gases.

Figure 3.2-3 shows a supply system for one fluid using the fluid rack for storage in the modules. This is similar to the baseline configuration and uses the fluids rack as both the transport structure and the storage volume for the gases.

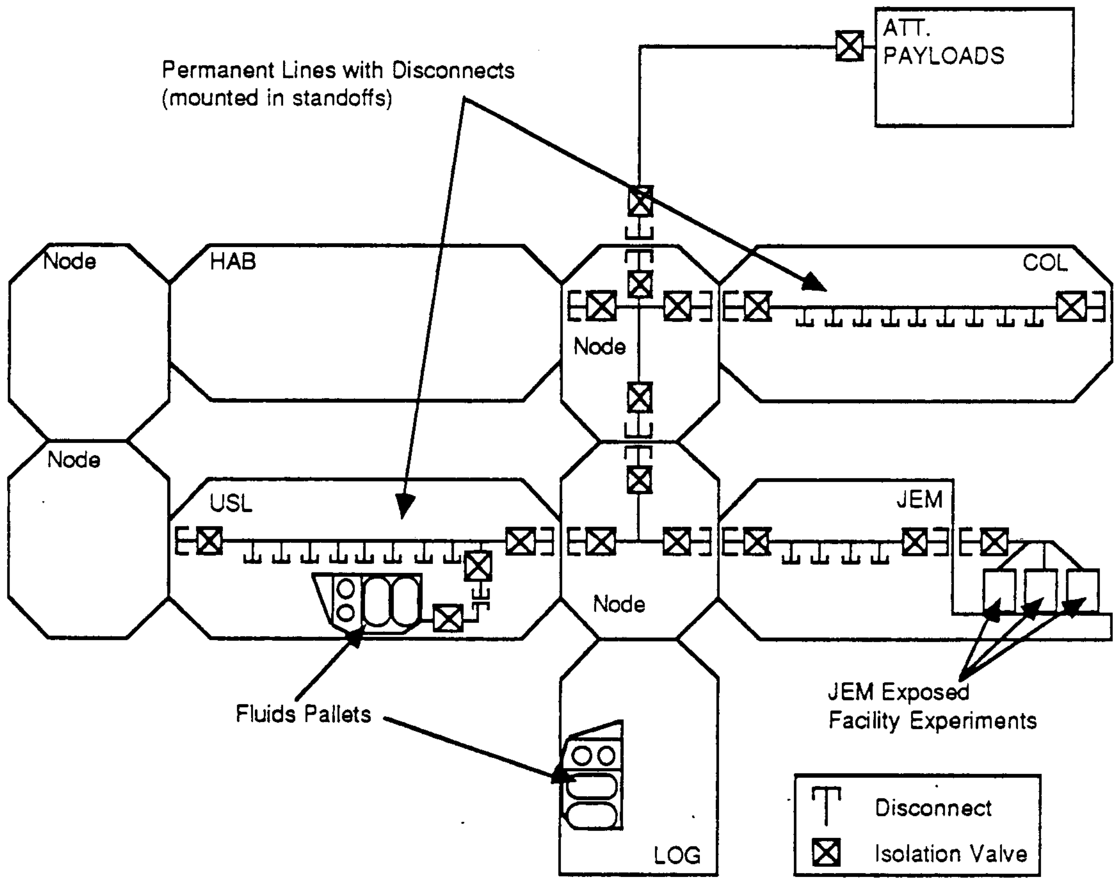

Figure 3.2-3 Fluids Rack Supply Configuration

Delivering fluids to the Space Station on a fluids pallet which is brought up on the Unpressurized Logistics Carrier (UPC) simplifies distribution to the attached payloads. This approach does not require penetations of the pressure shell between the storage vessel and the attached payloads. The fluids pallet is attached to the Space Station truss structure where it is connected to a line for each which goes to both the attached payloads and to the modules. Penetrations of the pressure shell are required at one of the unused module interfaces to transfer the gases inside the modules for use in the laboratories. Insulation and debris protection are required for the tanks and any lines which are outside of the modules. A diagram of this system for one fluid is shown in Figure 3.2-4.

Resupply of gases to the Space Station from tanks permanently mounted on the Pressurized Logistics Carrier requires penetrations of the pressure shell at both the PLC docking interface and an unused module interface of one of the nodes. Figure 3.2-5 shows how this configuration uses the same distribution systems used with the fluids rack supply configuration. This system may not make good use of the tankage on the PLC because the tanks may not be completely emptied before the PLC is due to be returned to earth.

A decrease in the total amount of fluid supplied to the Space Station may be achieved by recycling pure gases which have been discarded by the attached payloads. The current data available on the attached payload experiments which use argon and helium provides no information about the state in which these gases are supplied to the experiments or about the purity of the gases being

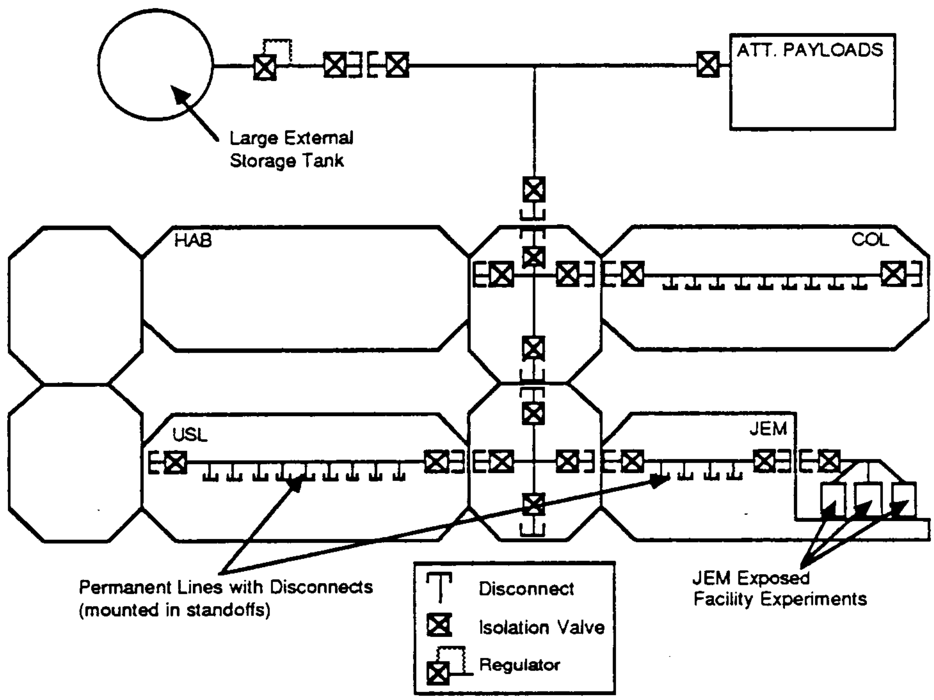

Figure 3.2-4 Fluid Supply System Using External Tankage on a Fluids Pallet (with Permanent Distribution System)

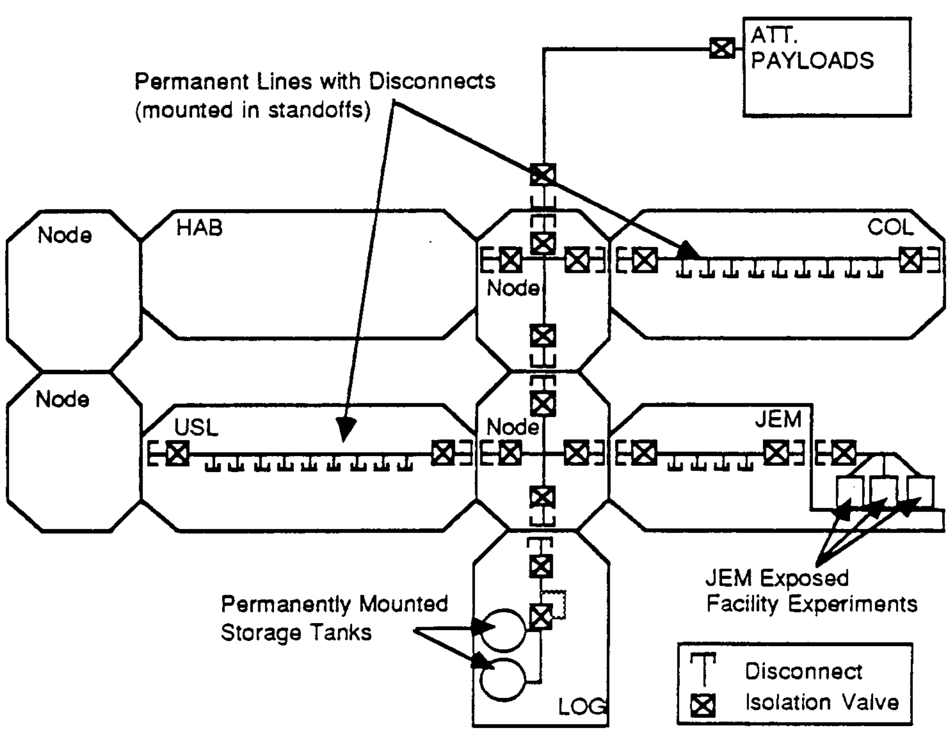

Figure 3.2-5 Resupply from Tanks Mounted in the Logistics Module

expelled from them. If the effluent gases are pure, they can be collected and compressed back into their respective distribution systems. This procedure, depicted in Figure 3.2-6, cuts down on the total amount of fluid which is being delivered to the Space Station without affecting any of the experiments. The only additional hardware required by these systems are the compressors required for recycling. Gas disposal lines are already required to avoid contamination of the environment.

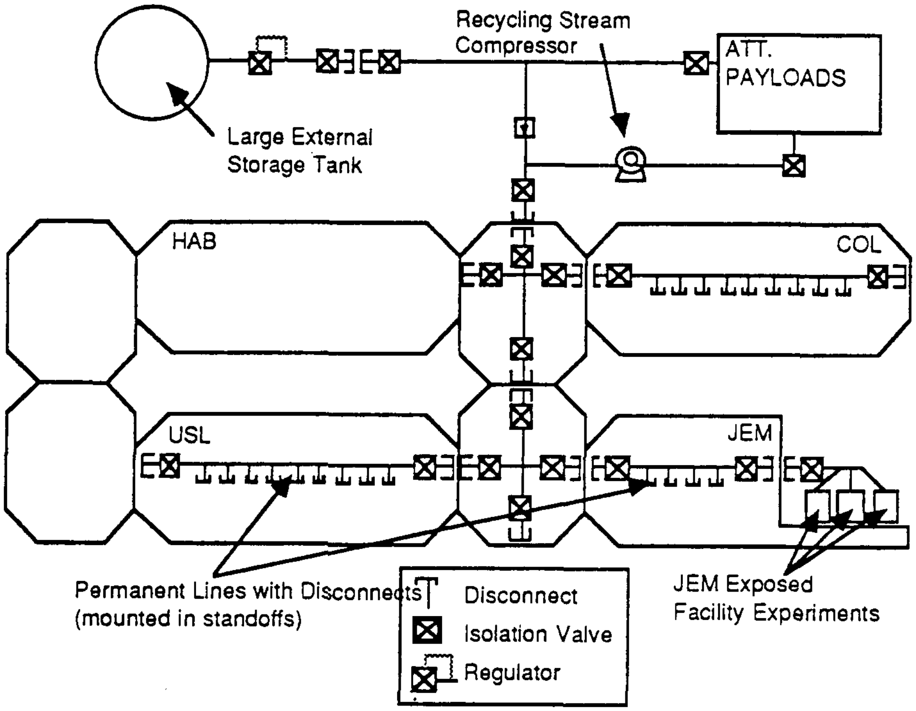

Figure 3.2-6 Reuse of Gaseous Waste from Attached Payloads

3.2.3 Distribution Configurations for Integrated Systems

Argon, carbon dioxide, and helium are required by all three laboratories, while only helium and argon are needed by the attached payloads. Distribution of the gases to the laboratories can be accomplished using either internal or external distribution lines or portable pressure tanks. A permanent internal distribution system requires installation of fluid lines within the utility runs of the nodes and modules as shown previously in Figure 3.2-2. Because provisions must be made for access to the fluid supply lines in any rack, permanent installation requires either a disconnect or a flex hose and disconnect for each fluid at each rack location. This type of system will require a large number of disconnects above and beyond the baseline quantity to connect the lines from module to module, and will also require space in the standoffs. A simple schematic of this configuration is shown in Figure 3.2-7. The argon and helium required by the atached payloads is piped directly to them through external lines which have both thermal and debris protection.

A permanent distribution system with external lines requires more insulation and debris protection hardware than a system with internal lines because of the greater amount of hardware it has that is exposed to space. There are fewer disconnects required, but assembly must take place on orbit and some room may still be required in the standoffs. Additionally, the disconnects are connections from the module to external lines, which require the manufacture of an additional penetration in each module's pressure shell. This configuration also transfers fluids directly to the

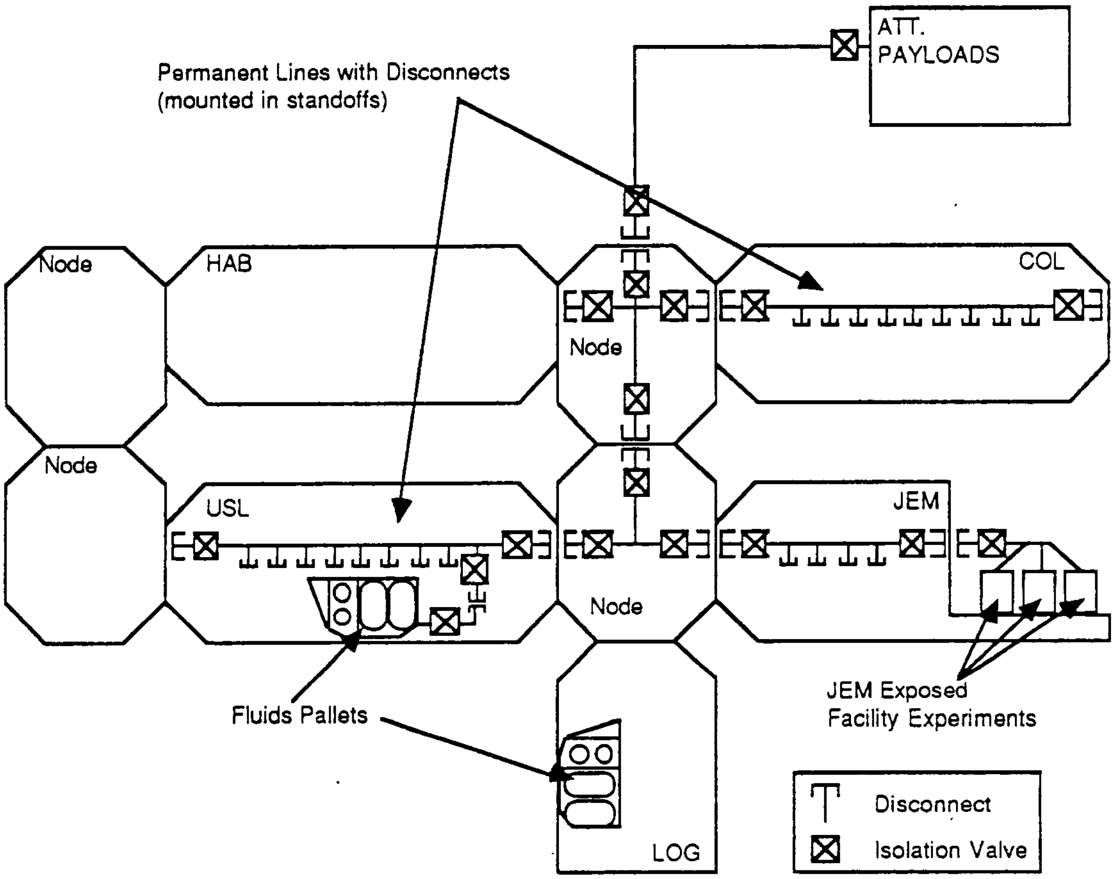

Figure 3.2-7 Permanently Mounted Gas Distribution System Schematic

attached payloads through external lines.

A flexible temporary system using lines that are not installed permanently in the standoffs can provide an alternative to the scarring required with permanent lines. These lines can be connected on one end to a disconnect at a supply source and at the other end to a disconnect on an experiment rack. The hoses can be moved from one experiment to another and after each move attached to the cabin walls by velcro or other fasteners. Attaching the hoses to the wall prevents obstruction of the passageways. There may have to be several supply source disconnects for each fluid and even different supply locations in order to accommodate closed hatch operations by some of the users, i.e. the Japanese Experimmtal Module. These requirements may create a need for a hybrid temporary/ permanent system which would include supply sources in each of the laboratory modules.

Pressure vessels can be used within the Space Station to provide the necessary flexibility for supplying the experiments with gases, but these vessels need not be returned to earth for refilling. Refill of these small tanks can be performed on-orbit from a supply system which incorporates larger storage tanks for supply from earth. The use of these larger tanks increases the mass fraction of supplied gas, which serves to decrease launch costs. Refill of the small pressure vessels can be performed by attaching them to a conveniently located disconnect, opening isolation valves on either side of the disconnect, and filling the tank to the desired pressure. More than one of these refill stations can be installed in one central location or a convenient spots throughout the modules.

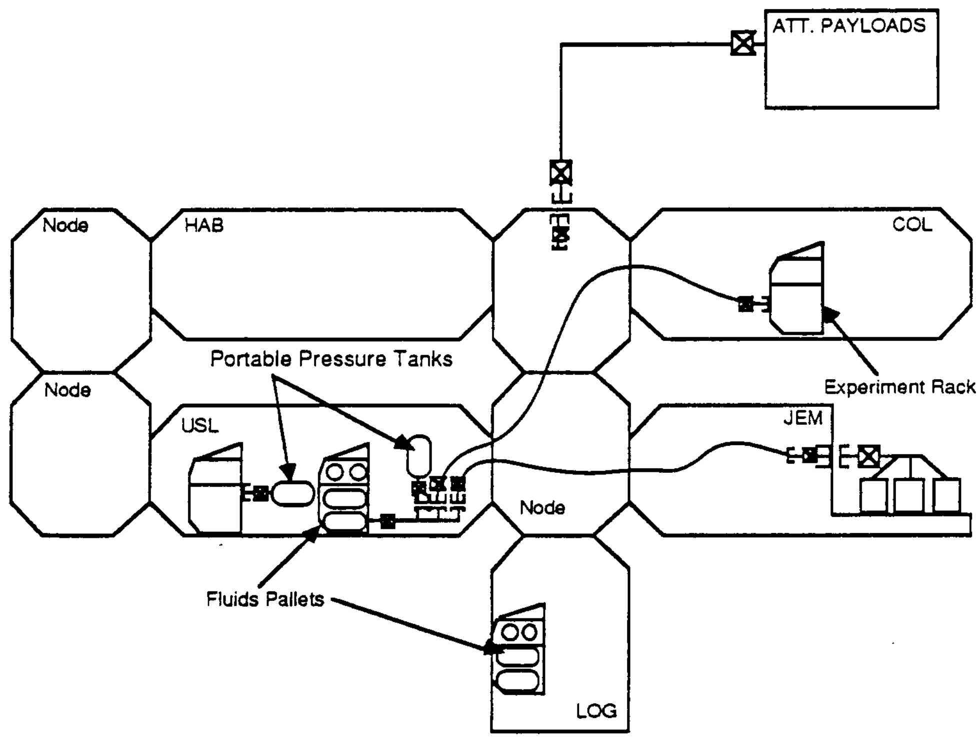

Figure 3.2-8 Distribution System Schematic with Temporary Supply Lines

A combination of the temporary line system and the portable tank system can provide the flexibility needed for closed hatch operations. This configuration is shown in Figure 3.2-8. The movable lines would be used for all but closed hatch operations, when portable pressure tanks would be used to supply those experiments that would be isolated. This combined system eliminates the need for constructing pemanent lines to more than one location within the Space Station. However, the use of flex lines which pass through the hatches presents a problem with rapid egress requirements. This problem limits the practicality of this configuration.

Open or closed-hatch operations can both be served using a concept with permanent lines in the nodes and flexible lines in the modules, as shown in Figure 3.2-9. This distribution system is suited to resupply from the Pressurized Logistics Carrier, from experient racks, or from external fluids pallets. This concept uses the baseline distribution system in the nodes while providing distribution system flexibility in the modules. Permanent lines in the utility runs with disconnects at the racks are alleviated to save space. It also eliminates the running of flexible lines in the nodes and between modules where safety hazards due to temporary lines may be imposed. With this system, a flexible line is connected to a disconnect at the module/node interface and routed to the experiment rack.

Growth and commonality considerations may also play a role in the design of the experiment gas distribution systems. If more laboratory modules requiring gas supplies are eventually added to the Space Station, distribution lines already available in the nodes will allow much simpler fluid connections and will avoid a great deal of on orbit construction. Installing these lines prior to launch also eliminates development costs incurred in designing more than one type of node.

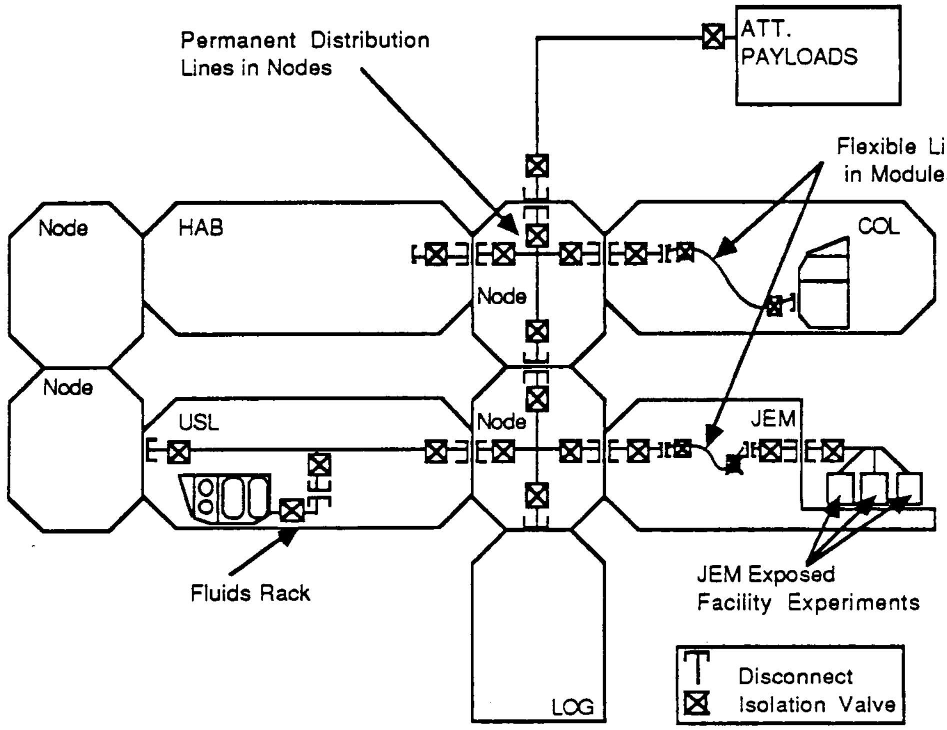

Figure 3.2-9 Temporary/Permanent Distribution System with Flexible Lines Within the Modules

3.2-1 Overall Configurations for Experiment Gas Supply

Several configurations have been developed to meet the supply requiremnts of all the experiment gas users. However, the overall optimum configuration for the Experient Gas Supply system has not been determined. Because of the large number of combinations of supply and distribution systems, the final selection will require more specific requirements about the number of users, usage timelines, supply pressures, and gas quantities.

4.0 INTEGRATED OXYGEN/HYDROGEN SYSTEM

There are several systems aboard the Space Station which use oxygen and/or hydrogen in their operation. There are also different sources for this oxygen and hydrogen. Table 4.0-1 contains a list of O_2 and H_2 users and sources.

Table 4.0-1 Oxygen and Hydrogen Sources and Users

Oxygen Users	Hydrogen Users
- ECLSS Crew (Respiration) Safe Haven Oxygen Supply HBC Operations Airlock Operations	- ECLSS Sabatier CO_2 Reduction
- Experiment Gas Supply USL Columbus JEM	- Experiment Gas Supply USL Columbus JEM
- Main O_2/H_2 Propulsion System	- Main O_2/H_2 Propulsion System
Oxygen Sources	**Hydrogen Sources**
- Water Electrolysis	- Water Electrolysis - ECLSS Bosch CO_2 Reduction

The reference configuration uses portable gas pressure vessels for supplying the gases that are used for the experiments. Because these vessels tend to be rather heavy, eliminating the cost of launching them benefits the Space Station program.

The Environmental Control and Life Support Subsystem (ECLSS) uses a recycling process which produces oxygen and hydrogen from water that is brought up as part of the crew's food. The water is reclaimed by the life support system after it has been ingested and eliminated by the crew's bodies. This water is then electrolyzed to produce oxygen and hydrogen. The oxygen is used for respiration and much of the hydrogen is used in the CO_2 reduction processes.

There are two types of carbon dioxide reduction processes that are being studied for use on the Space Station, the Bosch and Sabatier processes. The Bosch reacts hydrogen with CO_2 to produce solid carbon and water, using most of the hydrogen in the process. The water is recycled and the carbon is returned to earth on the Shuttle or deorbitted by other means. The Sabatier, on the other hand, reacts hydrogen with CO_2 to produce methane (CH_4) and water. All of the hydrogen is used up in this process without converting all the carbon dioxide. Again, the water is recycled. The remaining mixture of CO_2 /CH_4 is then discarded as waste or used for propulsion through resistojets. The quantities of the gases used and produced are discussed in Section 4.1.

The Propulsion System produces oxygen and hydrogen from water, also through the process of water electrolysis. The water used for this process must be obtained from the ground via the NSTS Shuttle or from one of the Space Station onboard systems, such as excess potable water from the ECLSS.

The Experiment Gas Supply provides oxygen and hydrogen, as well as other reagent gases to the experiments that require them. The reference confiuration delivers oxygen and hydrogen in portable gas containers which are brought to the Space Station specifically for that purpose; however these two gases may be obtained from electrolyzed water. The benefits of this resupply method are examined in Section 4.1.1 as part of the discussion of fully integrated systems.

4.0.1 Water Electrolysis Apparatus

Water electrolysis is the process of breaking down water into its constituents by passing an electrical current through it. There are several types of apparatus for performing water electrolysis, but only two that are known to work in microgravity environments. These two types, which are currently being studied for use on the Space Station, are the Potassium Hydroxide Electrolysis Unit (KOH), and the Solid Polymer Electrolyte Electrolysis Unit (SPE). There are different schemes for using these units, and different fluid conditions at which they will operate. The primary driver for the overall hydrogen/oxygen generation system is a need to store the gas at high pressure (1000 to 3000 psia) in order to reduce the storage tank volume and mass. Although the KOH unit operates with greater efficiency, the SPE electrolyzer may prove to be the better candidate because it can operate with a pressure rise across it, possibly allowing a high pressure outlet flow with a low pressure feed. Because of the design of the unit, the KOH electrolyzer cannot operate with a pressure rise across it.

4.1 INTEGRATION OF THE OXYGEN AND HYDROGEN SUPPLIES

The goal of integrating the oxygen and hydrogen supplies on Space Station into one system is to decrease the overall cost of providing the required Space Station functions. The specific savings achieved by integrating the oxygen and hydrogen systems come from decreasing the quantity of water that must be delivered to the Space Station, from eliminating the need for resupplying oxygen and hydrogen for experiment use, and from decreasing the amount of hardware that must be manufactured and launched.

One effective way of decreasing the amount of water that must be delivered to the Space Station is to increase the quantity of hydrogen in the oxygen/hydrogen propellant mixture. This increase in the amount of fuel decreases the mixture ratio, the ratio of oxidizer to fuel, used for the propellant. A decrease in the mixture ratio for oxygen/hydrogen thrusters has been shown to increase the propellant's specific impulse, which is a measure of the amount of propulsive force that may be obtained from a given quantity of propellant. The specific impulse, or I_{sp}, for O_2 /H_2 thrusters has been demonstrated to vary from 380 sec at a mixture ratio of 8:1 to 420 sec at 6:1. Increasing the specific impulse of the propellants decreases the quantity of propellant which must be delivered to the Space Station. The hydrogen for increasing the I_{sp} can be obtained from the ECLSS if the Bosch carbon dioxide reduction process is used, or from the the excess hydrogen produced when water is electrolyzed to produce the required amount of oxygen for the experiments.

4.1.1 Integration Level Candidates

Three levels of system integration were developed for the oxygen/hydrogen system: non-integrated, partially integrated, and fully integrated. The three levels refer to the level of sharing of hardware and fluids. The non-integrated systems entirely seperate hardware and fluid systems. The partially integrated systems share hardware and/or fluids between the ECLSS and Propulsion systems, but leave the Experiment Gas Supply as a completely seperate system. The reference system considered for this study was a partially integratred system. The non-integrated cases were included to show the quantity of the integraton benefits already achieved. The fully integrated systems share hardware and fluids between all three systems. The effects of all three integration levels on resupply and disposal quanities are shown in Table 4.1-1. The hardware descriptions included here are very brief and are only presented to illustrate the analysis of resupply and disposal quantities. A more complete evaluation of these hardware systems is included in Section 4.1.2, Integrated Hardware System Candidates. The option numbers included in parenthesis at the end of each description refer to the schematics in Section 4.1.2, while the lower case letters attached to them refer to the CO_2 reduction scheme.

The values in Table 4.1-1 were calculated using information on the ECLSS system mass balance as developed by Hamilton Standard and using propulsion impulse and experiment gas quantities as developed by Martin Marietta. The resupply values represent the combined quantity of those materials shown for all three systems. The disposal values reflect all the material that must be disposed of, with the exception that systems using the Sabatier process are not penalized for non-propulsively venting CO_2 /CH_4 mixture, due to the small expense required relative to deorbit costs.

Table 4.1-1 Consumables Resupply and Waste Disposal
(All masses are in lb_m per 90 days)

Integration Level	Version	Resupply			Disposal				Total*
		Water	Gases	Total	C(s)	CO_2/CH_4	H_2O	Total*	
Non-integrated									
Bosch	1	2932	209	3141	436	—	670	1106	4247
Sabatier	2	2932	209	3141	—	958	186	186	3327
Partially integrated									
Bosch (shared water only)	1	2263	209	2472	436	—	—	436	2908
Bosch	2	2081	209	2290	436	—	—	436	2726
Sabatier	3	2731	209	2940	—	958	—	0	2940
Sabatier w/ CO_2/CH_4	4	2380	209	2589	—	—	—	0	2589
Fully integrated									
Bosch	1	2200	—	2200	436	—	—	436	2636
Sabatier	2	2854	—	2854	—	958	—	0	2854
Sabatier w/ CO_2/CH_4	3	2504	—	2504	—	—	—	0	2504

* Does not include waste CO_2/CH_4 (No penalty for waste vented non-propulsively)

The relative cost of launching and deorbitting materials used on the Space Station has not yet been determined. A figure of approximately $3000 per pound launched was used in many of the Phase B Space Station trade studies with no figure set for the cost of returning materials to earth. Because of the restrictions on Shuttle landing weight, the cost of deorbiting materials may exceed that of launching them. In this section the data is presented only in terms of mass. The last column in Table 4.1-1 is a total of all masses (relevant to this study) that must be transported to and from the Space Station. Given a one to one ratio of launch to deorbit costs, this column would show which system is the least costly to operate. These costs will be examined in Section 4.2 along with the system hardware costs.

4.1.1.1 Non-Integrated Systems - Analysis was performed for two versions of the non-integrated level. The first is a system which uses the Bosch CO_2 reduction process. This process produces solid carbon which must be returned to earth in the Shuttle or deorbitted by some other method. In addition, the Bosch process produces a large quantity of excess potable water which, in the non-integrated case, must be disposed of. Because of the large quantity of this water it cannot be vented and must be deorbitted by some means. (option 1a)

The second version of the non-integrated level is a system which uses the Sabatier CO_2 reduction process. This process produces no solid carbon, instead it produces a mixture of carbon dioxide and methane as mentioned previously. This mixture can be stored and then vented when allowable. The cost of storing the mixture is insignificant relative to deorbit costs (unless they are zero) and is not figured into the transported total. The Sabatier process also produces a quantity of excess potable water, although it is much smaller than that from the Bosch. These facts lead to the conclusion that the Sabatier is a better choice when no integration is employed. (option 1b)

4.1.1.2 Partially Integrated Systems - Four versions of the partially integrated level were examined. The first version is in essence the same as the non-integrated Bosch example, with a water line added for transferring excess potable water from the ECLSS to the propulsion system. The water transferred makes no change in the operating characteristics of the system, it simply reduces the total quantity of water that must be supplied to the station by the amount shared and eliminates the need to deorbit waste water. The carbon produced is still a waste product and must be disposed of. This is the reference system for the cost comparison in Section 4.2. (option 2a)

Identical values of the resupply and disposal figures for the second version of the partially integrated level are obtained by analyzing two very different hardware systems. These systems both share water and hydrogen between the Bosch ECLSS and the Propulsion system. The difference lies in the level of hardware integration of the two systems. One system is much like the first partially-integrated version, using separate hardware systems which share fluids through transfer lines. In this case the excess hydrogen produced by the ECLSS is piped to the Propulsion system where it lowers the mixture ratio, and consequently reduces the amount of propellant required. This decreases both the launch and disposal costs. Only the solid carbon must be disposed of. The hardware costs remain essentially the same with slight additional expenses incurred for the hydrogen and water lines. (option 3)

The other hardware system which produces the second version results is a system which not only shares fluids, but also electrolysis units, dryers, and water storage facilities. Again the mixture ratio of the propellant gases is decreased, lowering the water resupply requirement. The carbon remains as waste and must be eliminated. This type of integration greatly decreases the cost of hardware by eliminating duplication. (options 4a,5a,6a)

The results for the third version of the partially integrated level are also produced using two different hardware systems which use the Sabatier CO_2 reduction process. One system is identical to the non-integrated Sabatier concept, with a water line added to transfer the excess water produced by the ECLSS to the propulsion system for use as propellant. As in the non-integrated case, disposal of the CO_2/CH_4 mixture produced is not penalized because of the ease with which it can be accomplished. This version recieves no benefit from integrating hydrogen systems since the Sabatier process gives off no excess hydrogen. (option 2b)

These same resupply and disposal results are also obtained from a hardware system which shares electrolysis units, dryers, and water storage facilities in addition to the fluids it shares. This level of hardware integration decreases the number of components which must be constructed, which lowers initial cost. (options 4b,5b,6b)

The fourth version of the partially integrated level is identical to the third with one exception. Again the same results apply to two hardware systems using Sabatier CO_2 reduction, one which only shares fluids, the other which shares fluids and hardware; however, the CO_2/CH_4 mixture is used in resistojets as a propellant to reduce overall resupply requirements. Although the mixture doesn't produce a great deal of impulse per given weight, the large quatity of it which is available produces a large amount of impulse. As shown in Table 4.1-1, the use of this thrust greatly decreases water delivery requirements, lowering operational costs. (option 2c, options 4c,5c,6c)

4.1.1.3 Fully Integrated Systems

Three versions of the fully integrated level were analyzed. All three are very similar to those partially integrated level hardware systems in versions two, three, and four which share hardware. However, the fully integrated versions also integrate the Experiment Gas Supply by using the electrolysis units to produce O_2 and H_2 for the experiments from water brought up instead of gases. Electrolyzing the correct quantity of water to produce enough oxygen for the experiments produces more hydrogen than can be used by them. Including this hydrogen in the propellant supply reduces the mixture ratio, raises the I_{sp}, and lowers the quantity of water that must be electrolyzed for propellant. This integration also eliminates the need for oxygen and hydrogen storage tanks and associated hardware, further reducing cost.

4.1.2 Integrated Hardware System Candidates

Nine candidate systems were evaluated to determine the optimum candidate for the integrated oxygen/hydrogen propulsion system, based on life cycle cost. The schematics that were developed for these nine "options" are shown in Figures 4.1-1 through 4.1-9, and Table 4.1-2 matches these options with the proper versions of the system integration levels. The schematics do not show all the hardware details of the ECLS system because much of the hardware is irrelevant to determining the cost differences between the various options. Those ECLSS functions that are shown inside the gray line are assumed identical except for the CO_2 reduction process.

Table 4.1-2 Relationship Between O_2/H_2 Integration Levels and Hardware System Schematics

Integration Levels	Version	CO_2 Reduction	Shared Entities	Schematic (Option)
Non-integrated	1	Bosch	None	1a
Non-integrated	2	Sabtier	None	1b
Partially integrated	1	Bosch	H_2O	2a
Partially integrated	2	Bosch	H_2O, H_2	3
Partially integrated	2	Bosch	Hdwr, H_2O, H_2, O_2	4a,5a,6a
Partially integrated	3	Sabatier	H_2O	2b
Partially integrated	3	Sabatier	Hdwr, H_2O, H_2, O_2	4b,5b,6b
Partially integrated	4	Sabatier	H_2O, CO_2/CH_4	2c (+ R-jets)
Partially integrated	4	Sabatier	Hdwr, All fluids*	4c,5c,6c (+ R-jets)
Fully integrated	1	Bosch	Hdwr, H_2O, H_2, O_2	7a,8a,9a
Fully integrated	2	Sabatier	Hdwr, H_2O, H_2, O_2	7b,8b,9b
Fully integrated	3	Sabatier	Hdwr, All fluids*	7c,8c,9c (+ R-jets)

* All fluids includes H_2O, H_2, O_2, CO_2/CH_4 mixture.

Propulsion system component lists are shown for options 1-3 where no hardware integration is considered between the systems. These component lists are replaced with O_2/H_2 system component lists which combine the ECLSS and propulsion systems into one O_2/H_2 system for Options 4-6, and also combine the EGS for Options 7-9. These primary lists are included with the descriptions of each option.

The hardware required for the two CO_2 reduction processes are assumed to be equal in cost for this comparison; however, the hardware requirements associated with these CO_2 reduction processes, such as tank sizes, are adjusted for the different versions. Because of these variations, notations have been added to the option numbers using lower case letters: "a" systems use Bosch, "b" systems use Sabatier, and "c" systems use Sabatier and burn the CO_2 /CH_4 mixture in resistojets. The ECLSS hardware that is relevant to the comparison is listed seperately in Table 4.1-3 for Options 1, 2, and 3, which do not share hardware between the systems, and is included in the integrated O_2/H_2 system component lists for all other options.

Table 4.1-3 ECLSS Component List for Options 1, 2a, 2b, 2c, and 3

Item	Qty.	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure Vessel, water storage	8	3.6 cu.ft	300	14.5	116.0	Sperical Bladder Tanks
Valve, latching solenoid, water	23	0.50	300	3.0	69.0	Max flowrate = 0.67 cu. ft/min
Valve, latching solenoid, hydrogen	16	0.25	300	2.0	32.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, oxygen	16	0.25	300	2.0	32.0	Max flowrate = 0.100 lbm/sec
Valve, torque motor, hydrogen	8	0.75	300 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
Valve, torque motor, oxygen	8	0.75	300 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
*Valve, vent/relief, nitrogen	8	0.50	300 setpoint	2.0	16.0	Pressurant disposal valve
*Regulator, constant pressure, N2	8	0.38	3000 in/300 out	3.0	24.0	Pressurant control, shutoff capability req'd
Dryer, hydrogen compatible	8	0.25	300	5.0	40.0	Max water removal = .044 lbm/hr
Dryer, oxygen compatible	8	0.25	300	5.0	40.0	Max water removal = .044 lbm/hr
Electrolysis Unit, SPE or KOH	4	0.25	300	300.0	1200.0	Max electrolysis rate = 2.0 lbm water/hr
Total Mass					1625.0	

* One item required per spherical bladder tank
**Except where units are specified

The Experiment Gas Supply hardware for Options 1-6, which do not integrate this system into the O_2/H_2 system, is listed in Table 4.1-4. The O_2/H_2 system component lists for Options 7-9 include the hardware required for supplying the experiment gases.

Table 4.1-4 EGS Component List for All the Variations of Options 1 - 6

Item	Qty.	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure Vessel, hydrogen storage	1	1.7 cu. ft.	2000	15.7	15.7	Composite tanks; shape not defined
Pressure Vessel, oxygen storage	2	13.9 cu. ft.	2000	125.4	250.8	Composite tanks; shape not defined
Disconnect, hydrogen, halves	2	0.25	2000	2.5	5.0	Required for buildup ops
Disconnect, oxygen, halves	2	0.25	2000	2.5	5.0	Required for buildup ops
Valve, latching solenoid, hydrogen	2	0.25	2000	2.5	5.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, oxygen	3	0.25	2000	2.5	7.5	Max flowrate = 0.100 lbm/sec
Total mass					289.0	

**Except where units are specified

Option 1, shown in Figure 4.1-1, is the only design that applies to the non-integrated level. This schematic shows three entirely seperate systems for ECLS, Propulsion, and Experiment Gas Supply. Constructing a system in this way, without any integration at all, drives up both the cost of hardware as well as the cost of resuppyling the station. This design has no requirement for using common hardware among the three systems. Hardware has already been developed to meet most of the component requirements, but some items, such as tanks, electrolysis units, and dryers still require development and testing. Developing these components for use in more than one system spreads out the development cost, but does nothing to reduce the manufacturing cost of building greater numbers of the components. Either Bosch or Sabatier CO_2 reduction can be used without affecting the results. Table 4.1-5 shows the component lists for this configuration.

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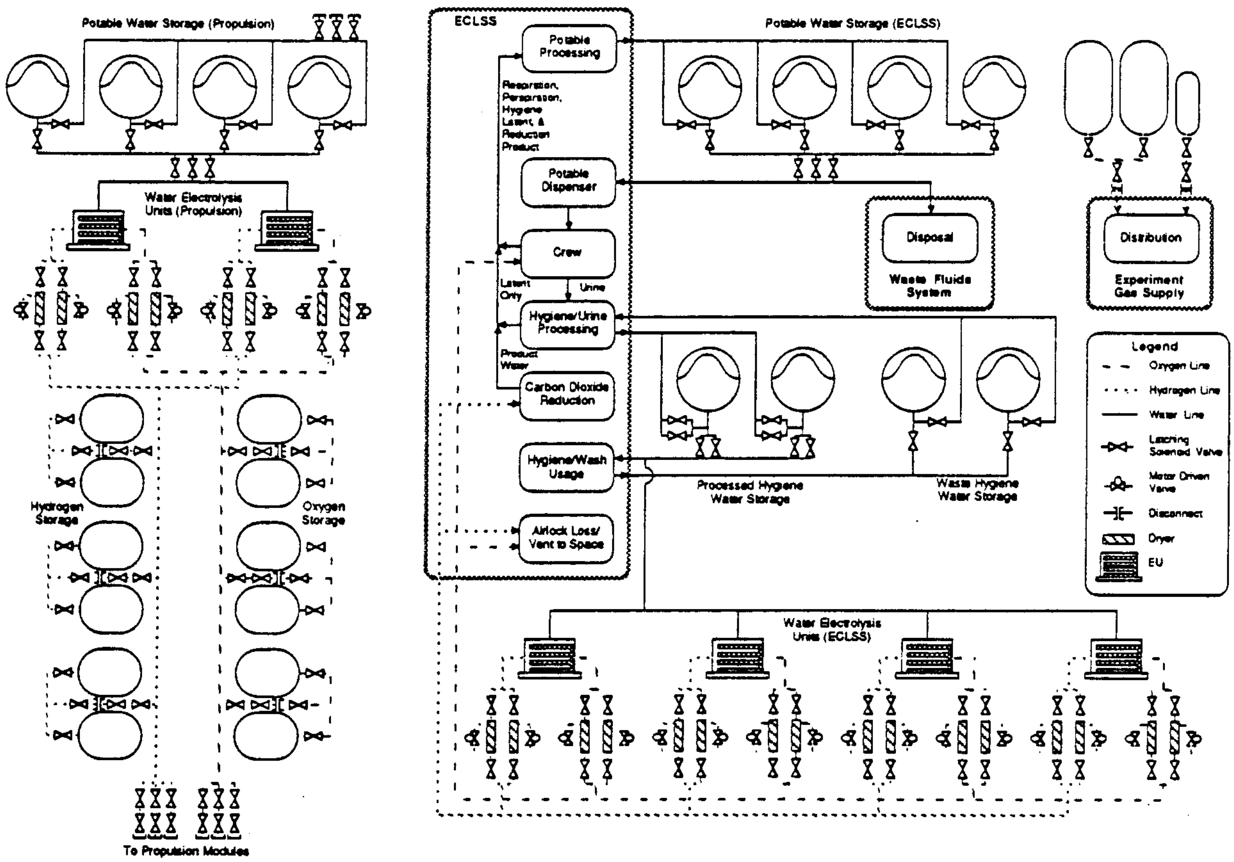

Figure 4.1-1 Option 1 - Non-Integrated ECLSS, Propulsion, and Experiment Gas Systems

Table 4.1-5 Option 1 Propulsion System Component List

Item	Qty.	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure Vessel, water storage	4	20.0 cu.ft.	300	68.1	272.3	Sperical Bladder Tanks
Pressure Vessel, hydrogen storage	6	38.3 cu.ft.	3000	504.7	3028.2	Composite tanks; shape not defined
Pressure Vessel, oxygen storage	6	14.5 cu.ft.	3000	193.7	1162.2	Composite tanks; shape not defined
Disconnect, water, halves	3	0.50	300	3.0	9.0	Triple redundant external seal
Disconnect, hydrogen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Disconnect, oxygen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Valve, latching solenoid, water	14	0.50	300	2.0	28.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, hydrogen	29	0.25	3000	2.0	58.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, oxygen	29	0.25	3000	2.0	58.0	Max flowrate = 0.100 lbm/sec
Valve, torque motor, hydrogen	4	0.75	3000 to vacuum	3.5	14.0	Large flow area req'd for vacuum pumping
Valve, torque motor, oxygen	4	0.75	3000 to vacuum	3.5	14.0	Large flow area req'd for vacuum pumping
*Valve, vent/relief, nitrogen	4	0.50	300 setpoint	2.0	8.0	Pressurant disposal valve
*Regulator, constant pressure, N2	4	0.38	3000 in/300 out	3.0	12.0	Pressurant control, shutoff capability req'd
Dryer, hydrogen compatible	4	0.25	3000	5.0	20.0	Max water removal = .044 lbm/hr
Dryer, oxygen compatible	4	0.25	3000	5.0	20.0	Max water removal = .044 lbm/hr
Electrolysis Unit, SPE, hyd. pump	2	0.25	300 in/3000 out	300.0	600.0	Max electrolysis rate = 2.0 lbm water/hr
Total mass					5348.7	
Total Mass of Propulsion, ECLSS, and EGS					7262.7	

* One item required per spherical bladder tank
**Except where units are specified

Figure 4.1-2 depicts Option 2, which has the lowest level of integration examined among the three systems. The Experiment Gas Supply is left entirely alone. There is no sharing of hardware between the ECLS and Propulsion systems, but excess potable water is transfered from the ECLSS storage tanks to the propulsion system. A small amount of additional hardware is required to connect the systems together and may include pumps to raise the water pressure to that of the propulsion water system. This schematic applies to two different versions of the partially integrated system: the Bosch with shared water only,. and the Sabatier with shared water. Their component lists are shown in Tables 4.1-6a and 4.1-6b. The sabatier with shared water can also benefit by using the waste CO_2/CH_4 mixture in resistojets to reduce the total amount of water required. This variaton of the system is not shown on a schematic, but the hardware required for it is shown in Table 4.1-6c.

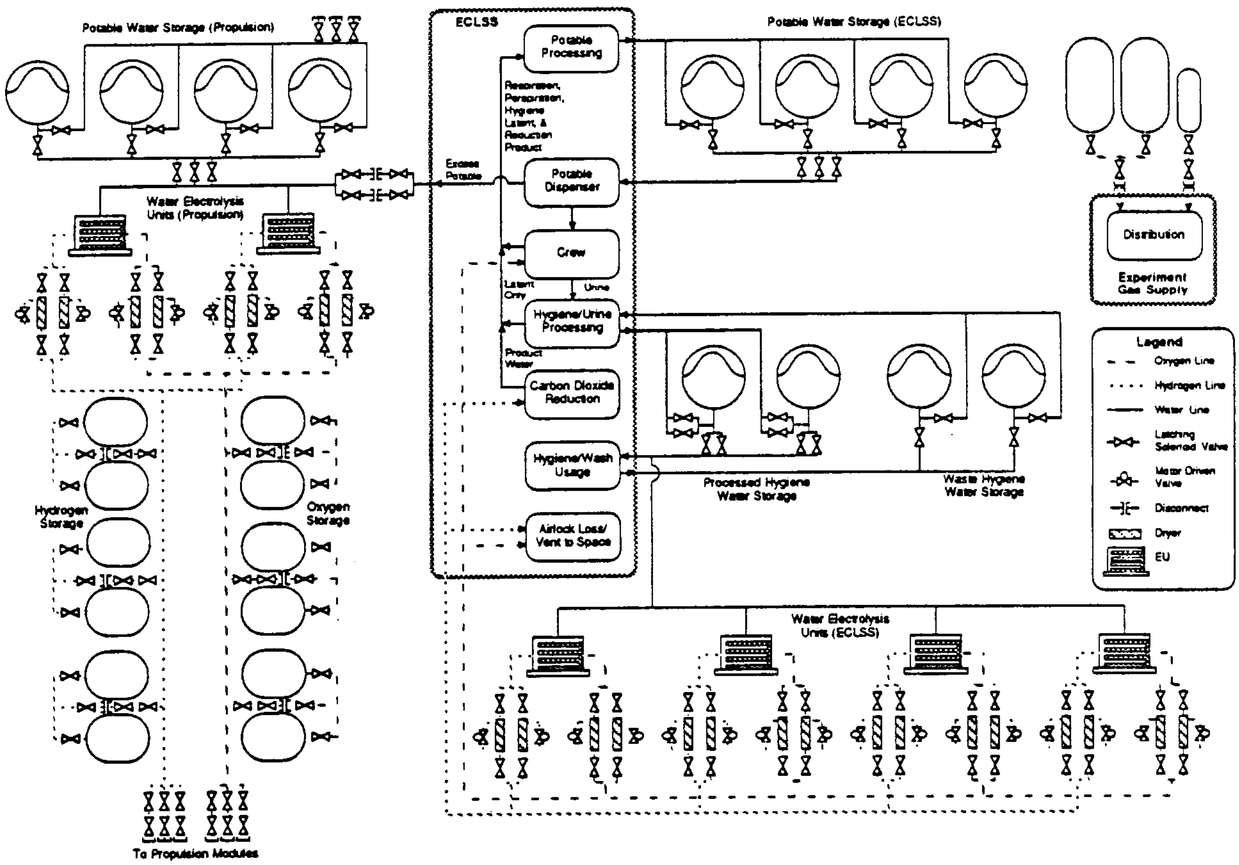

Figure 4.1-2 Option 2 - Partially Integrated O_2/H_2 System with Shared Water

Option 3,*- as shown in Figure 4.1-3, shows a partially integrated system in which the ECLSS shares both water and excess hydrogen from the Bosch process with the propulsion system. No integration with the Experiment Gas Supply is considered. This system applies only to the Bosch ECLSS system because only it produces excess hydrogen. Because of the different operating pressures between the ECLSS and propulsion systems, the hydrogen that is shared would have to be compressed up to the storage pressures required for the propellants. The component list for Option 3 is shown in Table 4.1-7.

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Table 4.1-6a Option 2a Propulsion System Component List

Item	Qty.	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure Vessel, water storage	4	15.1 cu.ft.	300	53.8	215.0	Sperical Bladder Tanks
Pressure Vessel, hydrogen storage	6	38.3 cu.ft.	3000	504.7	3028.2	Composite tanks; shape not defined
Pressure Vessel, oxygen storage	6	14.5 cu.ft.	3000	193.7	1162.2	Composite tanks; shape not defined
Disconnect, water, halves	7	0.50	300	3.0	21.0	Triple redundant external seal
Disconnect, hydrogen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Disconnect, oxygen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Valve, latching solenoid, water	18	0.50	300	2.0	36.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, hydrogen	29	0.25	3000	2.0	58.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, oxygen	29	0.25	3000	2.0	58.0	Max flowrate = 0.100 lbm/sec
Valve, torque motor, hydrogen	4	0.75	3000 to vacuum	3.5	14.0	Large flow area req'd for vacuum pumping
Valve, torque motor, oxygen	4	0.75	3000 to vacuum	3.5	14.0	Large flow area req'd for vacuum pumping
*Valve, vent/relief, nitrogen	4	0.50	300 setpoint	2.0	8.0	Pressurant disposal valve
*Regulator, constant pressure, N2	4	0.38	3000 in/300 out	3.0	12.0	Pressurant control, shutoff capability req'd
Dryer, hydrogen compatible	4	0.25	3000	5.0	20.0	Max water removal = .044 lbm/hr
Dryer, oxygen compatible	4	0.25	3000	5.0	20.0	Max water removal = .044 lbm/hr
Electrolysis Unit, SPE, hyd. pump	2	0.25	300 in/3000 out	300.0	600.0	Max electrolysis rate = 2.0 lbm water/hr
Total mass					5311.4	

Total Mass of Propulsion, ECLSS, and EGS 7225.4

* One item required per spherical bladder tank
**Except where units are specified

Table 4.1-6b Option 2b Propulsion System Component List

Item	Qty.	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure Vessel, water storage	4	18.3 cu.ft.	300	63.7	255.0	Sperical Bladder Tanks
Pressure Vessel, hydrogen storage	6	38.3 cu.ft.	3000	504.1	3024.6	Composite tanks; shape not defined
Pressure Vessel, oxygen storage	6	14.5 cu.ft.	3000	193.7	1162.2	Composite tanks; shape not defined
Disconnect, water, halves	7	0.50	300	3.0	21.0	Triple redundant external seal
Disconnect, hydrogen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Disconnect, oxygen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Valve, latching solenoid, water	18	0.50	300	2.0	36.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, hydrogen	29	0.25	3000	2.0	58.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, oxygen	29	0.25	3000	2.0	58.0	Max flowrate = 0.100 lbm/sec
Valve, torque motor, hydrogen	4	0.75	3000 to vacuum	3.5	14.0	Large flow area req'd for vacuum pumping
Valve, torque motor, oxygen	4	0.75	3000 to vacuum	3.5	14.0	Large flow area req'd for vacuum pumping
*Valve, vent/relief, nitrogen	4	0.50	300 setpoint	2.0	8.0	Pressurant disposal valve
*Regulator, constant pressure, N2	4	0.38	3000 in/300 out	3.0	12.0	Pressurant control, shutoff capability req'd
Dryer, hydrogen compatible	4	0.25	3000	5.0	20.0	Max water removal = .044 lbm/hr
Dryer, oxygen compatible	4	0.25	3000	5.0	20.0	Max water removal = .044 lbm/hr
Electrolysis Unit, SPE, hyd. pump	2	0.25	300 in/3000 out	300.0	600.0	Max electrolysis rate = 2.0 lbm water/hr
Total mass					5347.8	

Total Mass of Propulsion, ECLSS, and EGS 7261.8

* One item required per spherical bladder tank
**Except where units are specified

Table 4.1-6c Option 2c Propulsion System Component List

Item	Qty.	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure Vessel, water storage	4	16.0 cu.ft.	300	66.6	266.4	Sperical Bladder Tanks
Pressure Vessel, hydrogen storage	6	33.7 cu.ft.	3000	444.5	2667.0	Composite tanks; shape not defined
Pressure Vessel, oxygen storage	6	12.7 cu.ft.	3000	170.3	1021.8	Composite tanks; shape not defined
Disconnect, water, halves	7	0.50	300	3.0	21.0	Triple redundant external seal
Disconnect, hydrogen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Disconnect, oxygen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Valve, latching solenoid, water	18	0.50	300	2.0	36.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, hydrogen	29	0.25	3000	2.0	58.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, oxygen	29	0.25	3000	2.0	58.0	Max flowrate = 0.100 lbm/sec
Valve, torque motor, hydrogen	4	0.75	3000 to vacuum	3.5	14.0	Large flow area req'd for vacuum pumping
Valve, torque motor, oxygen	4	0.75	3000 to vacuum	3.5	14.0	Large flow area req'd for vacuum pumping
*Valve, vent/relief, nitrogen	4	0.50	300 setpoint	2.0	8.0	Pressurant disposal valve
*Regulator, constant pressure, N2	4	0.38	3000 in/300 out	3.0	12.0	Pressurant control, shutoff capability req'd
Dryer, hydrogen compatible	4	0.25	3000	5.0	20.0	Max water removal = .044 lbm/hr
Dryer, oxygen compatible	4	0.25	3000	5.0	20.0	Max water removal = .044 lbm/hr
Resistojet Assembly	1	0.25	30	41.8	41.8	Includes disconnects, valves, and thrusters
Electrolysis Unit, SPE, hyd. pump	2	0.25	300 in/3000 out	300.0	600.0	Max electrolysis rate = 2.0 lbm water/hr
Total Mass					4903.0	
Total Mass of Propulsion, ECLSS, and EGS					6817.0	

* One item required per spherical bladder tank
**Except where units are specified

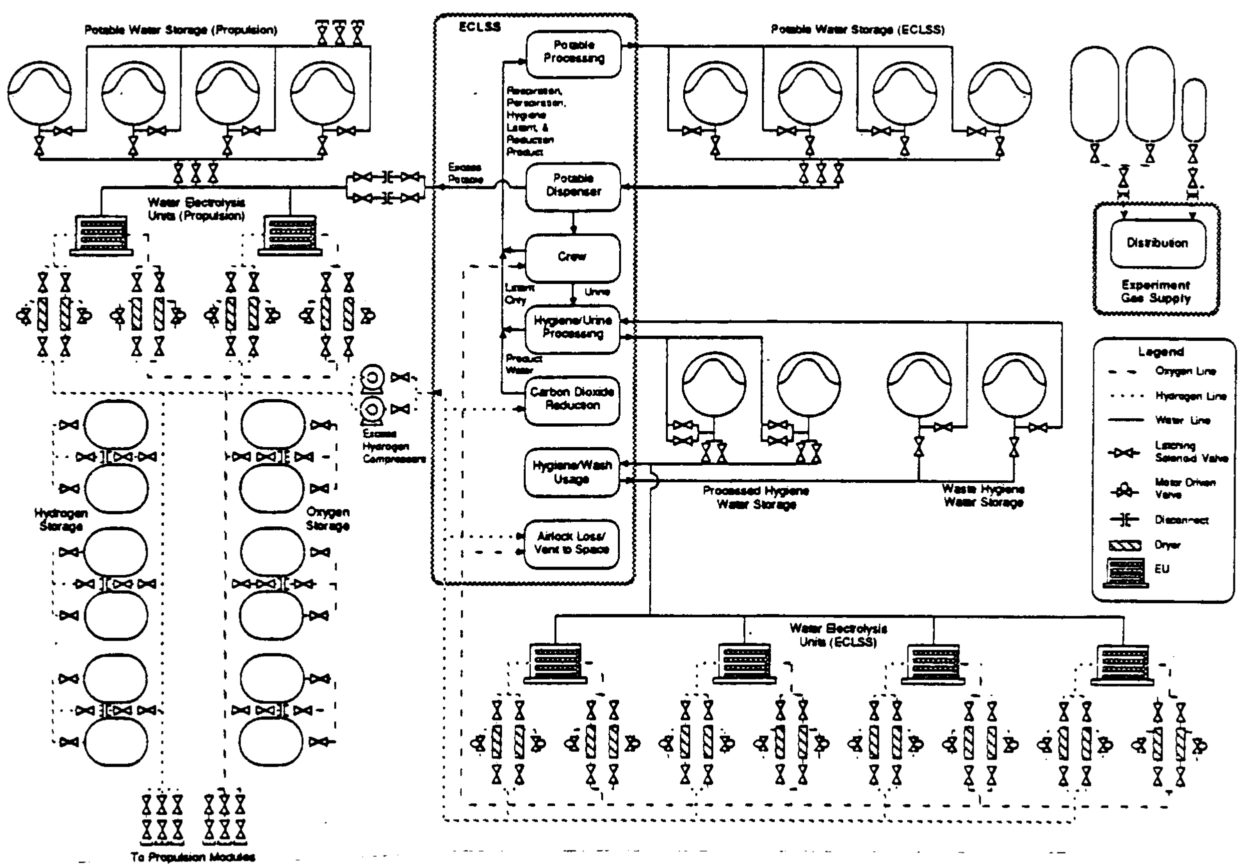

Figure 4.1-3 Option 3 - Partially Integrated O_2/H_2 System with Shared Water and Hydrogen

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Table 4.1-7 Option 3 Propulsion System Component List

Item	Qty.	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure Vessel, water storage	4	14.3 cu.ft.	300	50.9	203.4	Sperical Bladder Tanks
Pressure Vessel, hydrogen storage	6	40.6 cu.ft.	3000	534.3	3205.8	Composite tanks; shape not defined
Pressure Vessel, oxygen storage	6	13.6 cu.ft.	3000	182.0	1092.0	Composite tanks; shape not defined
Disconnect, water, halves	7	0.50	300	3.0	21.0	Triple redundant external seal
Disconnect, hydrogen, halves	13	0.25	3000	2.5	32.5	Required for buildup ops
Disconnect, oxygen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Valve, latching solenoid, water	18	0.50	300	2.0	36.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, hydrogen	31	0.25	3000	2.0	62.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, oxygen	29	0.25	3000	2.0	58.0	Max flowrate = 0.100 lbm/sec
Valve, torque motor, hydrogen	4	0.75	3000 to vacuum	3.5	14.0	Large flow area req'd for vacuum pumping
Valve, torque motor, oxygen	4	0.75	3000 to vacuum	3.5	14.0	Large flow area req'd for vacuum pumping
*Valve, vent/relief, nitrogen	4	0.50	300 setpoint	2.0	8.0	Pressurant disposal valve
*Regulator, constant pressure, N2	4	0.38	3000 in/300 out	3.0	12.0	Pressurant control, shutoff capability req'd
Dryer, hydrogen compatible	4	0.25	3000	5.0	20.0	Max water removal = .044 lbm/hr
Dryer, oxygen compatible	4	0.25	3000	5.0	20.0	Max water removal = .044 lbm/hr
Electrolysis Unit, SPE, hyd. pump	2	0.25	300	300.0	600.0	Max electrolysis rate = 2.0 lbm water/hr
Compressor, hydrogen	2	0.25	300 in/3000 out	25.0	50.0	
Total mass					5471.2	
Total Mass of Propulsion, ECLSS, and EGS					7385.2	

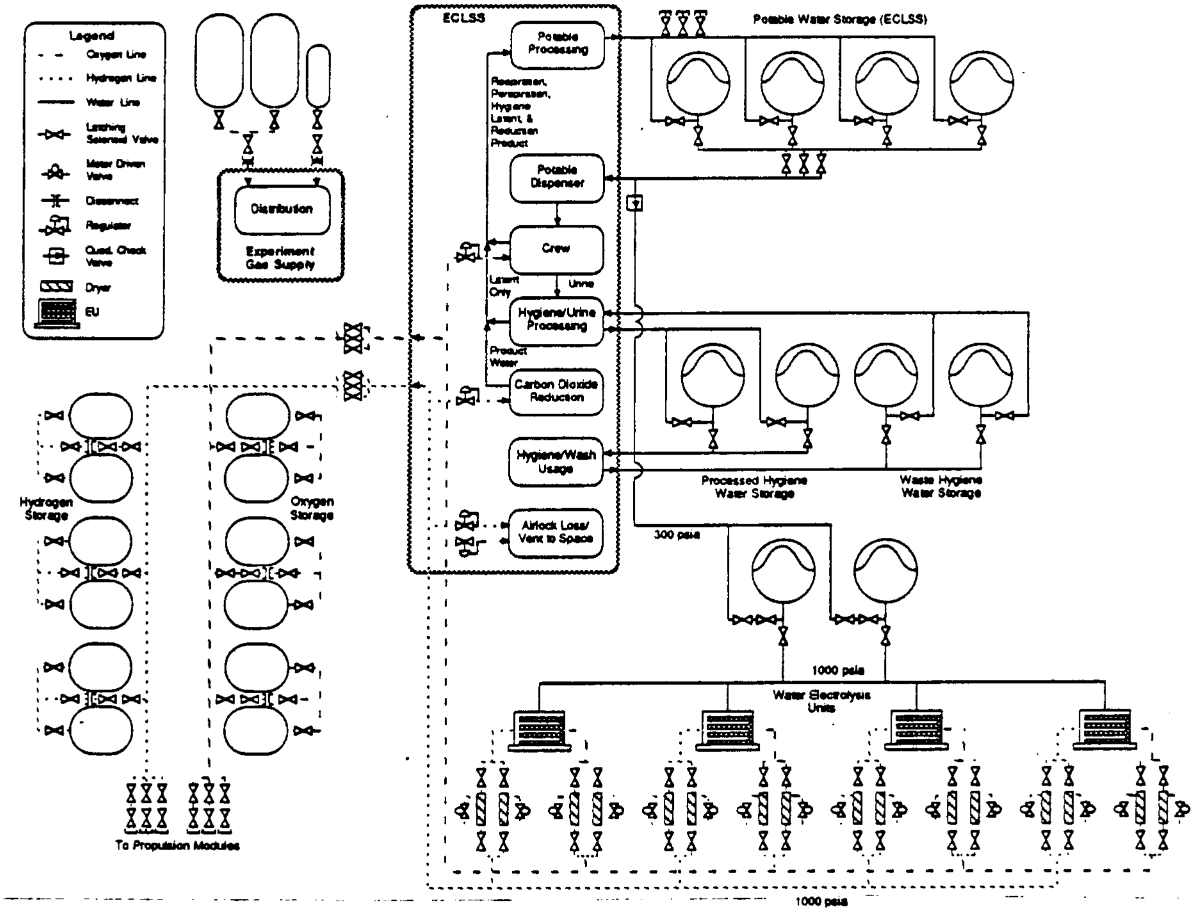

Figure 4.1-4 Option 4 - Partially Integrated O_2 /H_2 System with High Pressure Water Feed

Option 4 is the simplest system which combines the water storage and O_2/H_2 production functions of the ECLS and propulsion systems. It is shown in Figure 4.1-4. This system uses regulated high pressure water accumulators (or pumps) to raise the pressure of the water from a storage pressure of about 300 psia to around 3000 psia to for delivery to the electrolysis unit. The electrolysis occurs at high pressure and the product gases are stored for use in the propulsion system or regulated down for use in the ECLS system. The Option 4 schematic applies to three different versions of the partially integrated level. The first uses the Bosch CO_2 reduction process, the second uses the Sabatier, and the third also uses the Sabatier, but uses the waste CO_2/CH_4 mixture in resistojets to exploit its propulsive potential. Parts lists are shown in Tables 4.1-8a, 4.1-8b, and 4.1-8c for these three configurations. Table 4.1-8c includes the hardware required for using the mixture in resistojets even though it isn't shown in the schematic.

Table 4.1-8a Option 4a Integrated O_2/H_2 System Component List

Item	Qty.	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure Vessel, pot. water storage	4	14.3 cu.ft.	300	50.9	203.4	Sperical Bladder Tanks
Pressure Vessel, hyg. water storage	4	3.6 cu.ft.	300	14.5	58.0	Sperical Bladder Tanks
Pressure Vessel, h. p. water accum.	2	3.6 cu.ft.	3000	117.2	234.4	Sperical Bladder Tanks
Pressure Vessel, hydrogen storage	6	40.6 cu.ft.	3000	534.3	3205.8	Composite tanks; shape not defined
Pressure Vessel, oxygen storage	6	13.6 cu.ft.	3000	182.0	1092.0	Composite tanks; shape not defined
Disconnect, water, halves	3	0.50	300	3.0	9.0	Triple redundant external seal
Disconnect, hydrogen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Disconnect, oxygen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Valve, quad. check, water	1	0.50	300	2.0	2.0	Isolates hygiene and potable systems
Valve, latching solenoid, water	22	0.50	300	2.0	44.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, water	6	0.50	3000	2.0	12.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, hydrogen	40	0.25	3000	2.0	80.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, oxygen	40	0.25	3000	2.0	80.0	Max flowrate = 0.100 lbm/sec
Valve, torque motor, hydrogen	8	0.75	3000 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
Valve, torque motor, oxygen	8	0.75	3000 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
*Valve, vent/relief, nitrogen	8	0.50	300 setpoint	2.0	16.0	Pressurant disposal valve
*Valve, vent/relief, nitrogen	2	0.50	3000 setpoint	2.0	4.0	Pressurant disposal valve, h.p. accum.
*Regulator, constant press., nitrogen	8	0.38	3000 in/300 out	3.0	24.0	Pressurant control, shutoff capability req'd
Regulator, constant press., nitrogen	2	0.38	3000 in/~3000 out	3.0	6.0	Pressurant control, shutoff capability req'd
Regulator, constant press., hydrogen	2	0.25	3000 in/300 out	3.0	6.0	Regulates down for ECLSS systems
Regulator, constant press., oxygen	2	0.25	3000 in/300 out	3.0	6.0	Regulates down for ECLSS systems
Dryer, hydrogen compatible	8	0.25	3000	5.0	40.0	Max water removal = .044 lbm/hr
Dryer, oxygen compatible	8	0.25	3000	5.0	40.0	Max water removal = .044 lbm/hr
Electrolysis Unit, SPE or KOH	4	0.25	3000	300.0	1200.0	Max electrolysis rate = 2.0 lbm water/hr
Total mass					6463.6	
Total Mass of O2/H2 and EGS					6752.6	

* One item required per spherical bladder tank
**Except where units are specified

Option 5 also combines the water storage and O_2/H_2 production functions of the ECLS and propulsion systems. This design uses low pressure (~300 psia) electrolyzers for O_2/H_2 production. The choice of low pressure units decreases some component weights, eliminates the need for high pressure water accumulators (or pumps), and reduces the cost of electrolyzer development. This design uses compressors to obtain the pressures required for oxygen and hydrogen storage. The costs of developing and maintaining the pumps increase the overall cost of the system. The Option 5 schematic shown in Figure 4.1-5 applies to the same three integration levels as Option 4. The component lists are shown in Tables 4.1-9a and 4.1-9b for the Bosch and Sabatier versions, and in Table 4.1-9c for the Sabatier with resistojets. As with Option 4, the resistojet system is not included in the schematic.

(*Text continued on page 16*)

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Table 4.1-8b Option 4b Integrated O_2 /H_2 System Component List

Item	Qty.	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure Vessel, pot. water storage	4	18.3 cu.ft.	300	63.7	255.0	Sperical Bladder Tanks
Pressure Vessel, hyg. water storage	4	3.6 cu.ft.	300	14.5	58.0	Sperical Bladder Tanks
Pressure Vessel, h. p. water accum.	2	3.6 cu.ft.	3000	117.2	234.4	Sperical Bladder Tanks
Pressure Vessel, hydrogen storage	6	38.3 cu.ft.	3000	504.1	3024.6	Composite tanks; shape not defined
Pressure Vessel, oxygen storage	6	14.5 cu.ft.	3000	193.7	1162.2	Composite tanks; shape not defined
Disconnect, water, halves	3	0.50	300	3.0	9.0	Triple redundant external seal
Disconnect, hydrogen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Disconnect, oxygen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Valve, quad. check, water	1	0.50	300	2.0	2.0	Isolates hygiene and potable systems
Valve, latching solenoid, water	22	0.50	300	2.0	44.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, water	6	0.50	3000	2.0	12.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, hydrogen	40	0.25	3000	2.0	80.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, oxygen	40	0.25	3000	2.0	80.0	Max flowrate = 0.100 lbm/sec
Valve, torque motor, hydrogen	8	0.75	3000 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
Valve, torque motor, oxygen	8	0.75	3000 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
*Valve, vent/relief, nitrogen	8	0.50	300 setpoint	2.0	16.0	Pressurant disposal valve
*Valve, vent/relief, nitrogen	2	0.50	3000 setpoint	2.0	4.0	Pressurant disposal valve, h.p. accum.
*Regulator, constant press., nitrogen	8	0.38	3000 in/300 out	3.0	24.0	Pressurant control, shutoff capability req'd
Regulator, constant press., nitrogen	2	0.38	3000 in/~3000 out	3.0	6.0	Pressurant control, shutoff capability req'd
Regulator, constant press., hydrogen	2	0.25	3000 in/300 out	3.0	6.0	Regulates down for ECLSS systems
Regulator, constant press., oxygen	2	0.25	3000 in/300 out	3.0	6.0	Regulates down for ECLSS systems
Dryer, hydrogen compatible	8	0.25	3000	5.0	40.0	Max water removal = .044 lbm/hr
Dryer, oxygen compatible	8	0.25	3000	5.0	40.0	Max water removal = .044 lbm/hr
Electrolysis Unit, SPE or KOH	4	0.25	3000	300.0	1200.0	Max electrolysis rate = 2.0 lbm water/hr
Total mass					6404.1	
Total Mass of O2/H2 and EGS					6693.1	

Table 4.1-8c Option 4c Integrated O_2 /H_2 System Component List

Item	Qty.	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure Vessel, pot. water storage	4	16.0 cu.ft.	300	56.6	226.4	Sperical Bladder Tanks
Pressure Vessel, hyg. water storage	4	3.6 cu.ft.	300	14.5	58.0	Sperical Bladder Tanks
Pressure Vessel, h. p. water accum.	2	3.6 cu.ft.	3000	117.2	234.4	Sperical Bladder Tanks
Pressure Vessel, hydrogen storage	6	33.7 cu.ft.	3000	444.5	2667.0	Composite tanks; shape not defined
Pressure Vessel, oxygen storage	6	12.7 cu.ft.	3000	170.3	1021.8	Composite tanks; shape not defined
Disconnect, water, halves	3	0.50	300	3.0	9.0	Triple redundant external seal
Disconnect, hydrogen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Disconnect, oxygen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Valve, quad. check, water	1	0.50	300	2.0	2.0	Isolates hygiene and potable systems
Valve, latching solenoid, water	22	0.50	300	2.0	44.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, water	6	0.50	3000	2.0	12.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, hydrogen	40	0.25	3000	2.0	80.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, oxygen	40	0.25	3000	2.0	80.0	Max flowrate = 0.100 lbm/sec
Valve, torque motor, hydrogen	8	0.75	3000 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
Valve, torque motor, oxygen	8	0.75	3000 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
*Valve, vent/relief, nitrogen	8	0.50	300 setpoint	2.0	16.0	Pressurant disposal valve
*Valve, vent/relief, nitrogen	2	0.50	3000 setpoint	2.0	4.0	Pressurant disposal valve, h.p. accum.
*Regulator, constant press., nitrogen	8	0.38	3000 in/300 out	3.0	24.0	Pressurant control, shutoff capability req'd
Regulator, constant press., nitrogen	2	0.38	3000 in/~3000 out	3.0	6.0	Pressurant control, shutoff capability req'd
Regulator, constant press., hydrogen	2	0.25	3000 in/300 out	3.0	6.0	Regulates down for ECLSS systems
Regulator, constant press., oxygen	2	0.25	3000 in/300 out	3.0	6.0	Regulates down for ECLSS systems
Dryer, hydrogen compatible	8	0.25	3000	5.0	40.0	Max water removal = .044 lbm/hr
Dryer, oxygen compatible	8	0.25	3000	5.0	40.0	Max water removal = .044 lbm/hr
Resistojet Assembly	1	0.25	30	41.8	41.8	Includes disconnects, valves, and thrusters
Electrolysis Unit, SPE or KOH	4	0.25	3000	300.0	1200.0	Max electrolysis rate = 2.0 lbm water/hr
Total mass					5919.4	
Total Mass of O2/H2 and EGS					6208.4	

* One item required per spherical bladder tank
**Except where units are specified

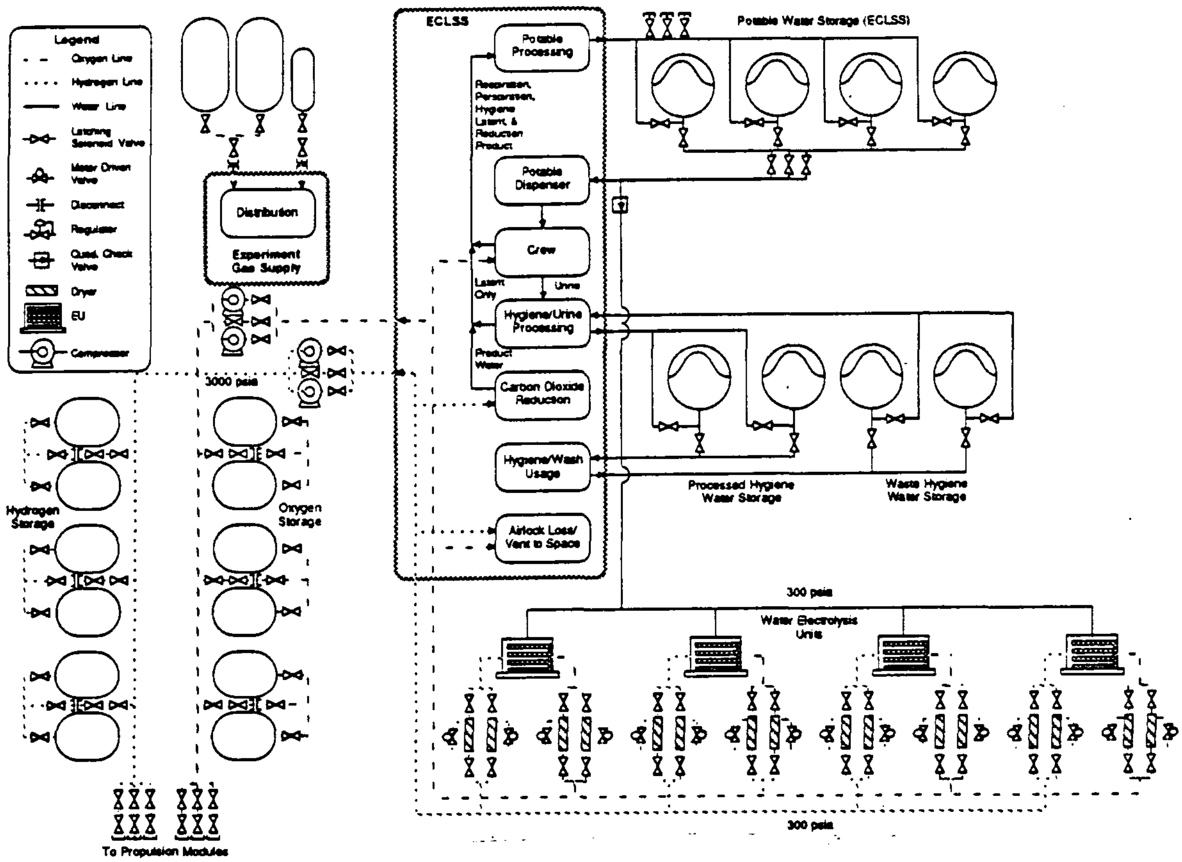

Figure 4.1-5 Option 5 - Partially Integrated O_2 /H_2 System with Compressors

Table 4.1-9a Option 5c Integrated O_2 /H_2 System Component List

Item	Qty.	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure Vessel, pot. water storage	4	14.3 cu.ft.	300	50.9	203.4	Sperical Bladder Tanks
Pressure Vessel, hyg. water storage	4	3.6 cu.ft.	300	14.5	58.0	Sperical Bladder Tanks
Pressure Vessel, hydrogen storage	6	40.6 cu.ft.	3000	534.3	3205.8	Composite tanks; shape not defined
Pressure Vessel, oxygen storage	6	13.6 cu.ft.	3000	182.0	1092.0	Composite tanks; shape not defined
Disconnect, water, halves	3	0.50	300	3.0	9.0	Triple redundant external seal
Disconnect, hydrogen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Disconnect, oxygen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Valve, latching solenoid, water	22	0.50	300	2.0	44.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, hydrogen	19	0.25	300	2.0	38.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, hydrogen	21	0.25	3000	2.0	42.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, oxygen	19	0.25	300	2.0	38.0	Max flowrate = 0.100 lbm/sec
Valve, latching solenoid, oxygen	21	0.25	3000	2.0	42.0	Max flowrate = 0.100 lbm/sec
Valve, torque motor, hydrogen	8	0.75	300 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
Valve, torque motor, oxygen	8	0.75	300 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
*Valve, vent/relief, nitrogen	8	0.50	300 setpoint	2.0	16.0	Pressurant disposal valve
Valve, quad. check, water	1	0.50	300	2.0	2.0	Isolates hygiene and potable systems
*Regulator, constant press., nitrogen	8	0.38	3000 in/300 out	3.0	24.0	Pressurant control, shutoff capability req'd
Dryer, hydrogen compatible	8	0.25	300	5.0	40.0	Max water removal = .044 lbm/hr
Dryer, oxygen compatible	8	0.25	300	5.0	40.0	Max water removal = .044 lbm/hr
Electrolysis Unit, SPE or KOH	4	0.25	300	300.0	1200.0	Max electrolysis rate = 2.0 lbm water/hr
Compressor, hydrogen	2	0.25	300 in/3000 out	25.0	50.0	
Comoressor, oxygen	2	0.25	300 in/3000 out	25.0	50.0	
Total mass					6295.2	
Total Mass of O2/H2 and EGS					6584.2	

Table 4.1-9b Option 5b Integrated O_2 /H_2 System Component List

Item	Qty.	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure Vessel, pot. water storage	4	18.3 cu.ft.	300	63.7	255.0	Sperical Bladder Tanks
Pressure Vessel, hyg. water storage	4	3.6 cu.ft.	300	14.5	58.0	Sperical Bladder Tanks
Pressure Vessel, hydrogen storage	6	38.3 cu.ft.	3000	504.1	3024.6	Composite tanks; shape not defined
Pressure Vessel, oxygen storage	6	14.5 cu.ft.	3000	193.7	1162.2	Composite tanks; shape not defined
Disconnect, water, halves	3	0.50	300	3.0	9.0	Triple redundant external seal
Disconnect, hydrogen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Disconnect, oxygen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Valve, latching solenoid, water	22	0.50	300	2.0	44.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, hydrogen	19	0.25	300	2.0	38.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, hydrogen	21	0.25	3000	2.0	42.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, oxygen	19	0.25	300	2.0	38.0	Max flowrate = 0.100 lbm/sec
Valve, latching solenoid, oxygen	21	0.25	3000	2.0	42.0	Max flowrate = 0.100 lbm/sec
Valve, torque motor, hydrogen	8	0.75	300 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
Valve, torque motor, oxygen	8	0.75	300 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
*Valve, vent/relief, nitrogen	8	0.50	300 setpoint	2.0	16.0	Pressurant disposal valve
Valve, quad. check, water	1	0.50	300	2.0	2.0	Isolates hygiene and potable systems
*Regulator, constant press., nitrogen	8	0.38	3000 in/300 out	3.0	24.0	Pressurant control, shutoff capability req'd
Dryer, hydrogen compatible	8	0.25	300	5.0	40.0	Max water removal = .044 lbm/hr
Dryer, oxygen compatible	8	0.25	300	5.0	40.0	Max water removal = .044 lbm/hr
Electrolysis Unit, SPE or KOH	4	0.25	300	300.0	1200.0	Max electrolysis rate = 2.0 lbm water/hr
Compressor, hydrogen	2	0.25	300 in/3000 out	25.0	50.0	
Compressor, oxygen	2	0.25	300 in/3000 out	25.0	50.0	
Total mass					6235.8	
Total Mass of O2/H2 and EGS					6524.8	

Table 4.1-9c Option 5c Integrated O_2 /H_2 System Component List

Item	Qty.	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure Vessel, pot. water storage	4	16.0 cu.ft.	300	56.6	226.4	Sperical Bladder Tanks
Pressure Vessel, hyg. water storage	4	3.6 cu.ft.	300	14.5	58.0	Sperical Bladder Tanks
Pressure Vessel, hydrogen storage	6	33.7 cu.ft.	3000	444.5	2667.0	Composite tanks; shape not defined
Pressure Vessel, oxygen storage	6	12.7 cu.ft.	3000	170.3	1021.8	Composite tanks; shape not defined
Disconnect, water, halves	3	0.50	300	3.0	9.0	Triple redundant external seal
Disconnect, hydrogen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Disconnect, oxygen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Valve, latching solenoid, water	22	0.50	300	2.0	44.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, hydrogen	19	0.25	300	2.0	38.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, hydrogen	21	0.25	3000	2.0	42.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, oxygen	19	0.25	300	2.0	38.0	Max flowrate = 0.100 lbm/sec
Valve, latching solenoid, oxygen	21	0.25	3000	2.0	42.0	Max flowrate = 0.100 lbm/sec
Valve, torque motor, hydrogen	8	0.75	300 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
Valve, torque motor, oxygen	8	0.75	300 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
*Valve, vent/relief, nitrogen	8	0.50	300 setpoint	2.0	16.0	Pressurant disposal valve
Valve, quad. check, water	1	0.50	300	2.0	2.0	Isolates hygiene and potable systems
*Regulator, constant press., nitrogen	8	0.38	3000 in/300 out	3.0	24.0	Pressurant control, shutoff capability req'd
Dryer, hydrogen compatible	8	0.25	300	5.0	40.0	Max water removal = .044 lbm/hr
Dryer, oxygen compatible	8	0.25	300	5.0	40.0	Max water removal = .044 lbm/hr
Resistojet Assembly	1	0.25	30	41.8	41.8	Includes disconnects, valves, and thrusters
Electrolysis Unit, SPE or KOH	4	0.25	300	300.0	1200.0	Max electrolysis rate = 2.0 lbm water/hr
Compressor, hydrogen	2	0.25	300 in/3000 out	25.0	50.0	
Compressor, oxygen	2	0.25	300 in/3000 out	25.0	50.0	
Total mass					5751.0	
Total Mass of O2/H2 and EGS					6040.0	

* One item required per spherical bladder tank
**Except where units are specified

Option 6, like Options 4 and 5, combines the ECLSS with the propulsion system and leaves the Experiment Gas Supply as a seperate entity. This option requires the least amount of hardware of any of the partially integrated systems because it uses electrolysis units with low inlet pressures and high outlet pressures instead of pumps, high pressure accumulators, or compressors. The pressure rise across the unit is achieved using a Solid Polymer Electrolysis unit. This unit is the only one that will allow the pressure across its cells because its design includes seperate compartments for O_2, H_2, and water. The development of this system may be more costly than the additional hardware required for Options 4 and 5. The parts lists for these concepts are shown in Tables 4.1-10a, 4.1-10b, and 4.1-10c.

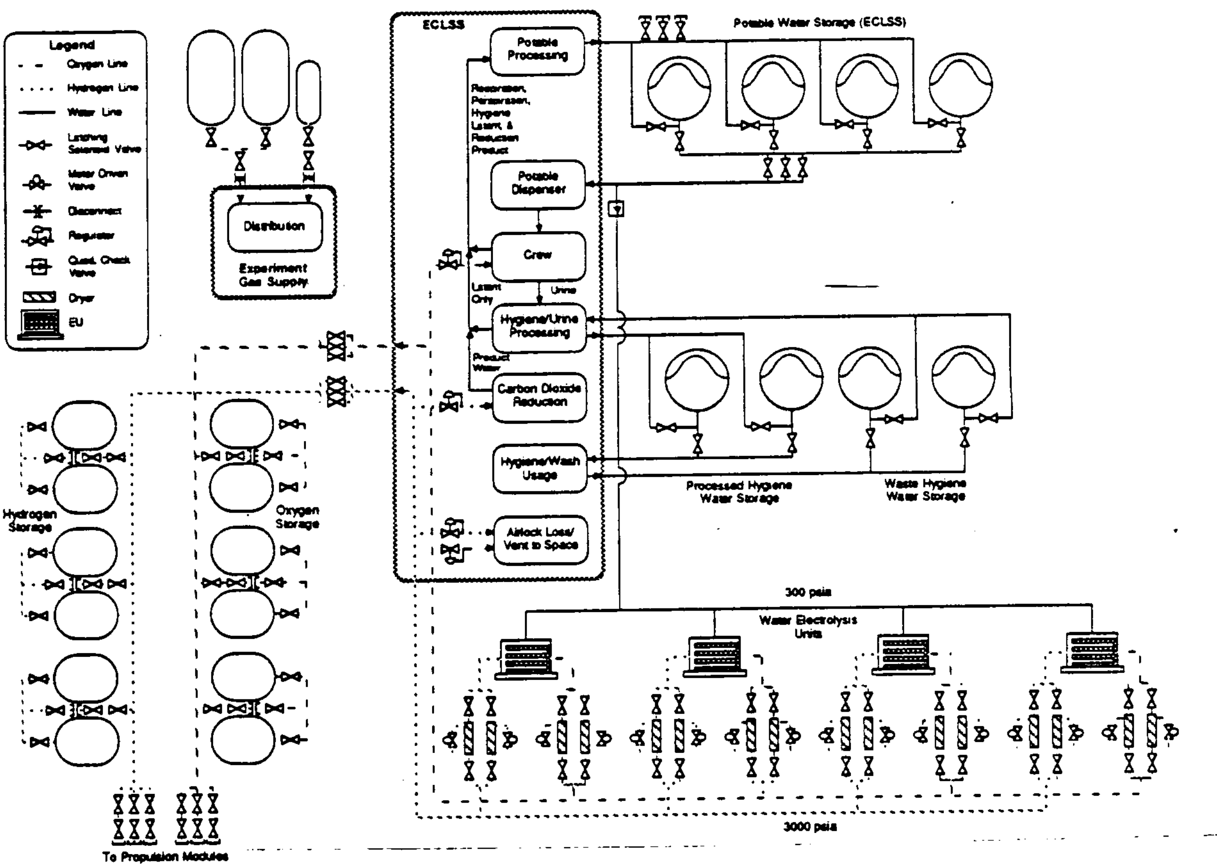

Figure 4.1-6 Option 6 - Partially Integrated O_2/H_2 System with Pumping Electrolysis Units

Options 7, 8, and 9 are in most ways identical to Options 4, 5, and 6, respectively. The one major difference between these fully integrated versions and their partially integrated counterparts is their integration of the Experiment Gas Supply with the already combined ECLSS/propulsion functions. This integration eliminates the requirement for dedicated oxygen and hydrogen storage for the experiments, and decreases the total resupply mass by supplying O_2 and H_2 in the form of water. When the proper quantity of water is electrolyzed to produce the required oxygen, too much hydrogen is produced. This excess hydrogen is added to the propulsion stores, which increases the specific impulse of the propellants and lowers the overall propellant mass required. The parts lists for the different versions of these systems are included in Tables 4.1-11a-c, 4.1-12a-c, and 4.1-13a-c.

(*Text continued on page 24*)

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Table 4.1-10a Option 6a Integrated O_2/H_2 System Component List

Item	Qty.	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure Vessel, pot. water storage	4	14.3 cu.ft.	300	50.9	203.4	Sperical Bladder Tanks
Pressure Vessel, hyg. water storage	4	3.6 cu.ft.	300	14.5	58.0	Sperical Bladder Tanks
Pressure Vessel, hydrogen storage	6	40.6 cu.ft.	3000	534.3	3205.8	Composite tanks; shape not defined
Pressure Vessel, oxygen storage	6	13.6 cu.ft.	3000	182.0	1092.0	Composite tanks; shape not defined
Disconnect, water, halves	3	0.50	300	3.0	9.0	Triple redundant external seal
Disconnect, hydrogen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Disconnect, oxygen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Valve, quad. check, water	1	0.50	300	2.0	2.0	Isolates hygiene and potable systems
Valve, latching solenoid, water	22	0.50	300	2.0	44.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, hydrogen	40	0.25	3000	2.0	80.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, oxygen	40	0.25	3000	2.0	80.0	Max flowrate = 0.100 lbm/sec
Valve, torque motor, hydrogen	8	0.75	3000 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
Valve, torque motor, oxygen	8	0.75	3000 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
*Valve, vent/relief, nitrogen	8	0.50	300 setpoint	2.0	16.0	Pressurant disposal valve
*Regulator, constant press., nitrogen	8	0.38	3000 in/300 out	3.0	24.0	Pressurant control, shutoff capability req'd
Regulator, constant press., hydrogen	2	0.25	3000 in/300 out	3.0	6.0	Regulates down for ECLSS systems
Regulator, constant press., oxygen	2	0.25	3000 in/300 out	3.0	6.0	Regulates down for ECLSS systems
Dryer, hydrogen compatible	8	0.25	3000	5.0	40.0	Max water removal = .044 lbm/hr
Dryer, oxygen compatible	8	0.25	3000	5.0	40.0	Max water removal = .044 lbm/hr
Electrolysis Unit, SPE, hyd. pump	4	0.25	3000	300.0	1200.0	Max electrolysis rate = 2.0 lbm water/hr
Total mass					6207.2	
Total Mass of O2/H2 and EGS					6496.2	

* One item required per spherical bladder tank
**Except where units are specified

Table 4.1-10b Option 6b Integrated O_2/H_2 System Component List

Item	Qty.	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure Vessel, pot. water storage	4	18.3 cu.ft.	300	63.7	254.8	Sperical Bladder Tanks
Pressure Vessel, hyg. water storage	4	3.6 cu.ft.	300	14.5	58.0	Sperical Bladder Tanks
Pressure Vessel, hydrogen storage	6	38.3 cu.ft.	3000	504.1	3024.6	Composite tanks; shape not defined
Pressure Vessel, oxygen storage	6	14.5 cu.ft.	3000	193.7	1162.2	Composite tanks; shape not defined
Disconnect, water, halves	3	0.50	300	3.0	9.0	Triple redundant external seal
Disconnect, hydrogen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Disconnect, oxygen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Valve, quad. check, water	1	0.50	300	2.0	2.0	Isolates hygiene and potable systems
Valve, latching solenoid, water	22	0.50	300	2.0	44.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, hydrogen	40	0.25	3000	2.0	80.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, oxygen	40	0.25	3000	2.0	80.0	Max flowrate = 0.100 lbm/sec
Valve, torque motor, hydrogen	8	0.75	3000 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
Valve, torque motor, oxygen	8	0.75	3000 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
*Valve, vent/relief, nitrogen	8	0.50	300 setpoint	2.0	16.0	Pressurant disposal valve
*Regulator, constant press., nitrogen	8	0.38	3000 in/300 out	3.0	24.0	Pressurant control, shutoff capability req'd
Regulator, constant press., hydrogen	2	0.25	3000 in/300 out	3.0	6.0	Regulates down for ECLSS systems
Regulator, constant press., oxygen	2	0.25	3000 in/300 out	3.0	6.0	Regulates down for ECLSS systems
Dryer, hydrogen compatible	8	0.25	3000	5.0	40.0	Max water removal = .044 lbm/hr
Dryer, oxygen compatible	8	0.25	3000	5.0	40.0	Max water removal = .044 lbm/hr
Electrolysis Unit, SPE, hyd. pump	4	0.25	3000	300.0	1200.0	Max electrolysis rate = 2.0 lbm water/hr
Total mass					6147.6	
Total Mass of O2/H2 and EGS					6436.6	

* One item required per spherical bladder tank
**Except where units are specified

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Table 4.1-10c Option 6c Propulsion System Component List

Item	Qty.	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure Vessel, pot. water storage	4	16.0 cu.ft.	300	56.6	226.4	Sperical Bladder Tanks
Pressure Vessel, hyg. water storage	4	3.6 cu.ft.	300	14.5	58.0	Sperical Bladder Tanks
Pressure Vessel, hydrogen storage	6	33.7 cu.ft.	3000	444.5	2667.0	Composite tanks; shape not defined
Pressure Vessel, oxygen storage	6	12.7 cu.ft.	3000	170.3	1021.8	Composite tanks; shape not defined
Disconnect, water, halves	3	0.50	300	3.0	9.0	Triple redundant external seal
Disconnect, hydrogen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Disconnect, oxygen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Valve, quad. check, water	1	0.50	300	2.0	2.0	Isolates hygiene and potable systems
Valve, latching solenoid, water	22	0.50	300	2.0	44.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, hydrogen	40	0.25	3000	2.0	80.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, oxygen	40	0.25	3000	2.0	80.0	Max flowrate = 0.100 lbm/sec
Valve, torque motor, hydrogen	8	0.75	3000 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
Valve, torque motor, oxygen	8	0.75	3000 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
*Valve, vent/relief, nitrogen	8	0.50	300 setpoint	2.0	16.0	Pressurant disposal valve
*Regulator, constant press., nitrogen	8	0.38	3000 in/300 out	3.0	24.0	Pressurant control, shutoff capability req'd
Regulator, constant press., hydrogen	2	0.25	3000 in/300 out	3.0	6.0	Regulates down for ECLSS systems
Regulator, constant press., oxygen	2	0.25	3000 in/300 out	3.0	6.0	Regulates down for ECLSS systems
Dryer, hydrogen compatible	8	0.25	3000	5.0	40.0	Max water removal = .044 lbm/hr
Dryer, oxygen compatible	8	0.25	3000	5.0	40.0	Max water removal = .044 lbm/hr
Resistojet Assembly	1	0.25	30	41.8	41.8	Includes disconnects, valves, and thrusters
Electrolysis Unit, SPE, hyd. pump	4	0.25	3000	300.0	1200.0	Max electrolysis rate = 2.0 lbm water/hr
Total mass					5663.0	
Total Mass of O2/H2 and EGS					5952.0	

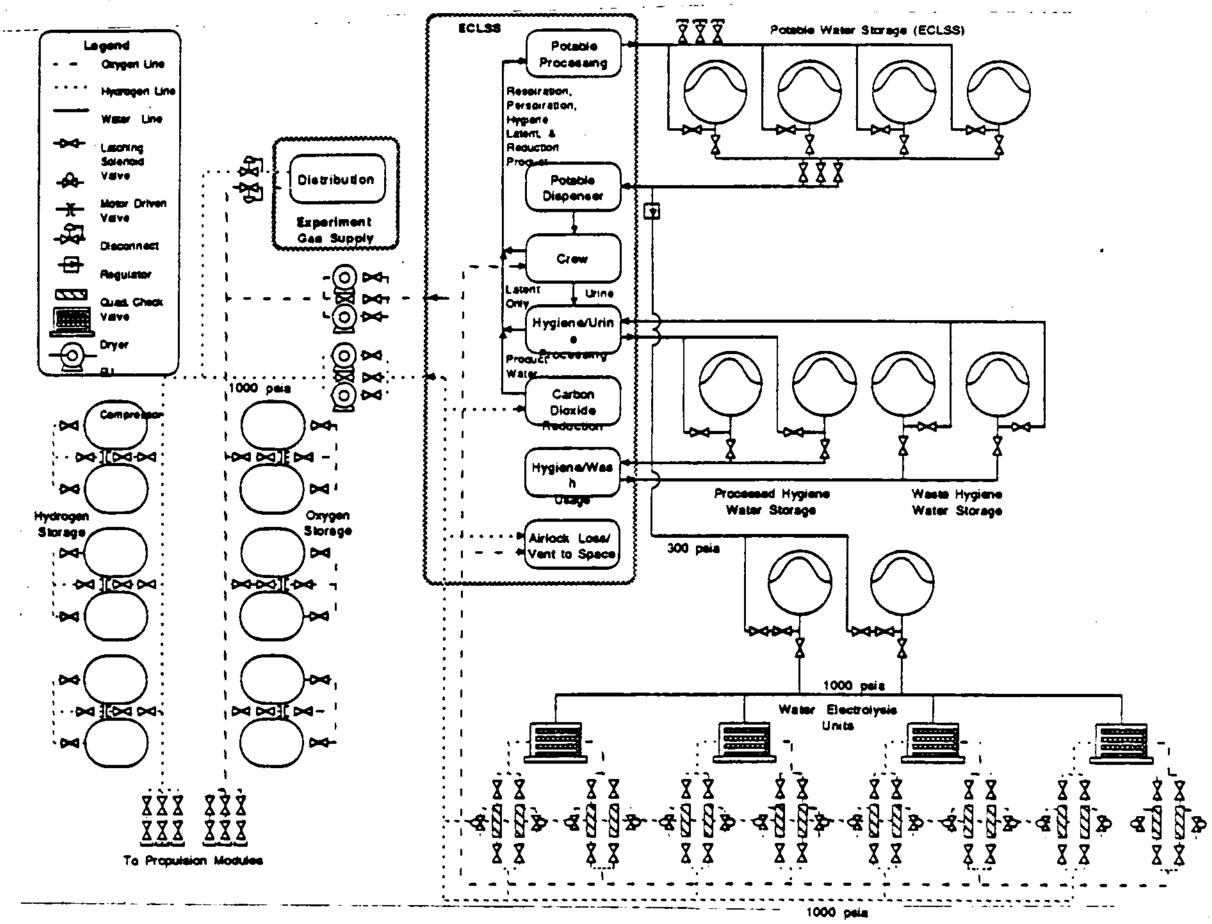

Figure 4.1-7 Option 7 - Fully Integrated O_2/H_2 System with High Pressure Water Feed

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Table 4.1-11a Option 7a Integrated O_2/H_2 System Component List

Item	Qty.	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure Vessel, pot. water storage	4	14.7 cu.ft.	300	52.3	209.2	Sperical Bladder Tanks
Pressure Vessel, hyg. water storage	4	3.6 cu.ft.	300	14.5	58.0	Sperical Bladder Tanks
Pressure Vessel, h. p. water accum.	2	3.6 cu.ft.	3000	117.2	234.4	Sperical Bladder Tanks
Pressure Vessel, hydrogen storage	6	42.2 cu.ft.	3000	554.5	3327.0	Composite tanks; shape not defined
Pressure Vessel, oxygen storage	6	14.5 cu.ft.	3000	193.7	1162.2	Composite tanks; shape not defined
Disconnect, water, halves	3	0.50	300	3.0	9.0	Triple redundant external seal
Disconnect, hydrogen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Disconnect, oxygen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Valve, latching solenoid, water	22	0.50	300	2.0	44.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, water	6	0.50	3000	2.0	12.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, hydrogen	40	0.25	3000	2.0	80.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, oxygen	40	0.25	3000	2.0	80.0	Max flowrate = 0.100 lbm/sec
Valve, torque motor, hydrogen	8	0.75	3000 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
Valve, torque motor, oxygen	8	0.75	3000 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
*Valve, vent/relief, nitrogen	8	0.50	300 setpoint	2.0	16.0	Pressurant disposal valve
*Valve, vent/relief, nitrogen	2	0.50	3000 setpoint	2.0	4.0	Pressurant disposal valve
Valve, quad. check, water	1	0.50	300	2.0	2.0	Isolates hygiene and potable systems
*Regulator, constant press., nitrogen	8	0.38	3000 in/300 out	3.0	24.0	Pressurant control, shutoff capability req'd
Regulator, constant press., nitrogen	2	0.38	3000 in/~3000 out	3.0	6.0	Pressurant control, shutoff capability req'd
Regulator, constant press., hydrogen	1	0.25	3000 in/300 out	3.0	3.0	Regulates down for EGS systems
Regulator, constant press., oxygen	1	0.25	3000 in/300 out	3.0	3.0	Regulates down for EGS systems
Dryer, hydrogen compatible	8	0.25	3000	5.0	40.0	Max water removal = .044 lbm/hr
Dryer, oxygen compatible	8	0.25	3000	5.0	40.0	Max water removal = .044 lbm/hr
Electrolysis Unit, SPE or KOH	4	0.25	3000	300.0	1200.0	Max electrolysis rate = 2.0 lbm water/hr
Total mass					6654.8	

* One item required per spherical bladder tank
**Except where units are specified

Table 4.1-11b Option 7b Integrated O_2/H_2 System Component List

Item	Qty.	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure Vessel, pot. water storage	4	19.1 cu.ft.	300	66.6	266.3	Sperical Bladder Tanks
Pressure Vessel, hyg. water storage	4	3.6 cu.ft.	300	14.5	58.0	Sperical Bladder Tanks
Pressure Vessel, h. p. water accum.	2	3.6 cu.ft.	3000	117.2	234.4	Sperical Bladder Tanks
Pressure Vessel, hydrogen storage	6	39.7 cu.ft.	3000	522.9	3137.4	Composite tanks; shape not defined
Pressure Vessel, oxygen storage	6	13.8 cu.ft.	3000	184.9	1109.4	Composite tanks; shape not defined
Disconnect, water, halves	3	0.50	300	3.0	9.0	Triple redundant external seal
Disconnect, hydrogen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Disconnect, oxygen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Valve, latching solenoid, water	22	0.50	300	2.0	44.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, water	6	0.50	3000	2.0	12.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, hydrogen	40	0.25	3000	2.0	80.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, oxygen	40	0.25	3000	2.0	80.0	Max flowrate = 0.100 lbm/sec
Valve, torque motor, hydrogen	8	0.75	3000 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
Valve, torque motor, oxygen	8	0.75	3000 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
*Valve, vent/relief, nitrogen	8	0.50	300 setpoint	2.0	16.0	Pressurant disposal valve
*Valve, vent/relief, nitrogen	2	0.50	3000 setpoint	2.0	4.0	Pressurant disposal valve
Valve, quad. check, water	1	0.50	300	2.0	2.0	Isolates hygiene and potable systems
*Regulator, constant press., nitrogen	8	0.38	3000 in/300 out	3.0	24.0	Pressurant control, shutoff capability req'd
Regulator, constant press., nitrogen	2	0.38	3000 in/~3000 out	3.0	6.0	Pressurant control, shutoff capability req'd
Regulator, constant press., hydrogen	1	0.25	3000 in/300 out	3.0	3.0	Regulates down for EGS systems
Regulator, constant press., oxygen	1	0.25	3000 in/300 out	3.0	3.0	Regulates down for EGS systems
Dryer, hydrogen compatible	8	0.25	3000	5.0	40.0	Max water removal = .044 lbm/hr
Dryer, oxygen compatible	8	0.25	3000	5.0	40.0	Max water removal = .044 lbm/hr
Electrolysis Unit, SPE or KOH	4	0.25	3000	300.0	1200.0	Max electrolysis rate = 2.0 lbm water/hr
Total mass					6469.5	

* One item required per spherical bladder tank
**Except where units are specified

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Table 4.1-11c Option 7c Integrated O_2/H_2 System Component List

Item	Qty.	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure Vessel, pot. water storage	4	16.9 cu.ft.	300	59.5	237.9	Sperical Bladder Tanks
Pressure Vessel, hyg. water storage	4	3.6 cu.ft.	300	14.4	57.6	Sperical Bladder Tanks
Pressure Vessel, h. p. water accum.	2	3.6 cu.ft.	3000	117.2	234.4	Sperical Bladder Tanks
Pressure Vessel, hydrogen storage	6	35.1 cu.ft.	3000	463.7	2782.2	Composite tanks; shape not defined
Pressure Vessel, oxygen storage	6	12.2 cu.ft.	3000	164.4	986.4	Composite tanks; shape not defined
Disconnect, water, halves	3	0.50	300	3.0	9.0	Triple redundant external seal
Disconnect, hydrogen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Disconnect, oxygen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Valve, latching solenoid, water	22	0.50	300	2.0	44.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, water	6	0.50	3000	2.0	12.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, hydrogen	40	0.25	3000	2.0	80.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, oxygen	40	0.25	3000	2.0	80.0	Max flowrate = 0.100 lbm/sec
Valve, torque motor, hydrogen	8	0.75	3000 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
Valve, torque motor, oxygen	8	0.75	3000 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
*Valve, vent/relief, nitrogen	8	0.50	300 setpoint	2.0	16.0	Pressurant disposal valve
*Valve, vent/relief, nitrogen	2	0.50	3000 setpoint	2.0	4.0	Pressurant disposal valve
Valve, quad. check, water	1	0.50	300	2.0	2.0	Isolates hygiene and potable systems
*Regulator, constant press., nitrogen	8	0.38	3000 in/300 out	3.0	24.0	Pressurant control, shutoff capability req'd
Regulator, constant press., nitrogen	2	0.38	3000 in/~3000 out	3.0	6.0	Pressurant control, shutoff capability req'd
Regulator, constant press., hydrogen	1	0.25	3000 in/300 out	3.0	3.0	Regulates down for EGS systems
Regulator, constant press., oxygen	1	0.25	3000 in/300 out	3.0	3.0	Regulates down for EGS systems
Dryer, hydrogen compatible	8	0.25	3000	5.0	40.0	Max water removal = .044 lbm/hr
Dryer, oxygen compatible	8	0.25	3000	5.0	40.0	Max water removal = .044 lbm/hr
Resistojet Assembly	1	0.25	30	41.8	41.8	Includes disconnects, valves, and thrusters
Electrolysis Unit, SPE or KOH	4	0.25	3000	300.0	1200.0	Max electrolysis rate = 2.0 lbm water/hr
Total mass					6004.3	

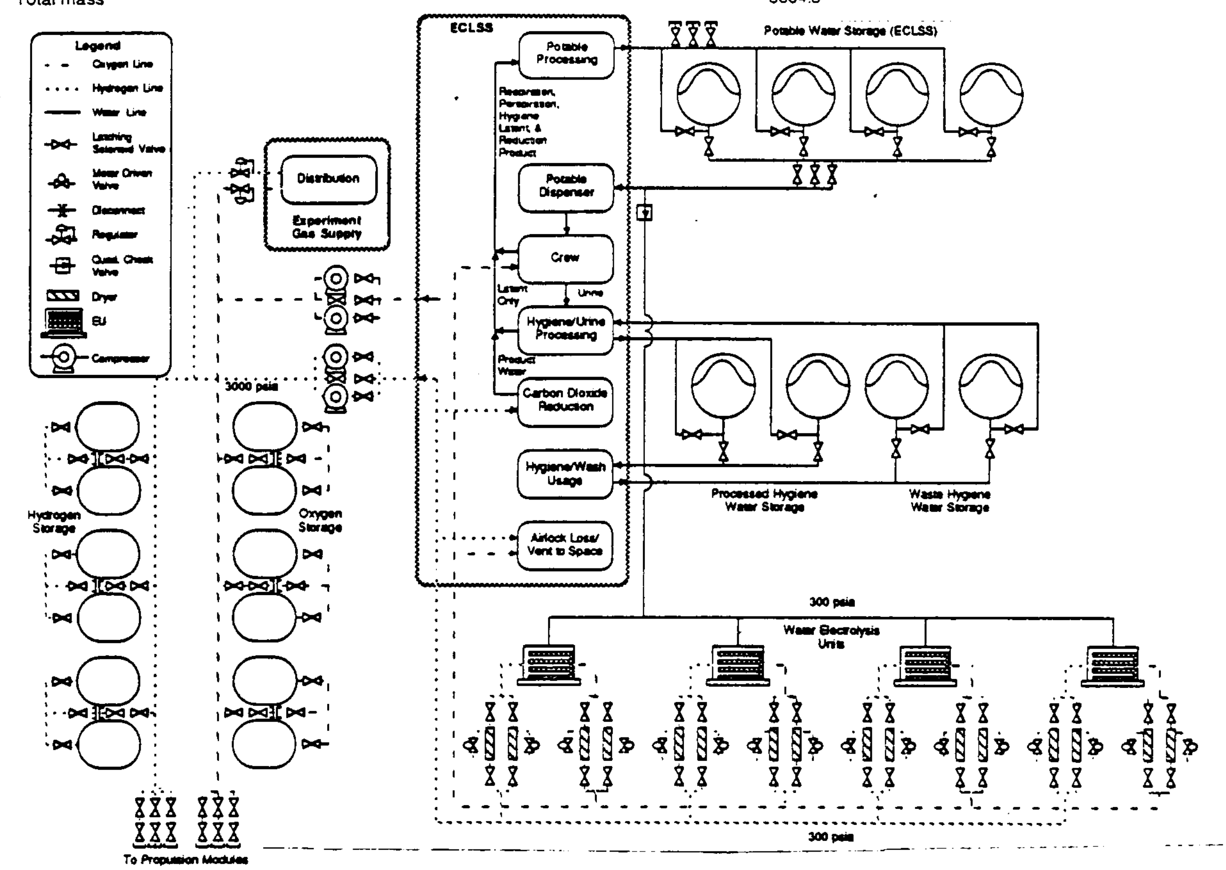

Figure 4.1-8 Option 8 - Fully Integrated O_2/H_2 System with Compressors

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Table 4.1-12a Option 8a Integrated O_2 /H_2 System Component List

Item	Qty.	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure Vessel, pot. water storage	4	14.7 cu.ft.	300	52.3	209.2	Sperical Bladder Tanks
Pressure Vessel, hyg. water storage	4	3.6 cu.ft.	300	14.5	58.0	Sperical Bladder Tanks
Pressure Vessel, hydrogen storage	6	42.2 cu.ft.	3000	554.5	3327.0	Composite tanks; shape not defined
Pressure Vessel, oxygen storage	6	14.5 cu.ft.	3000	193.7	1162.2	Composite tanks; shape not defined
Disconnect, water, halves	3	0.50	300	3.0	9.0	Triple redundant external seal
Disconnect, hydrogen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Disconnect, oxygen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Valve, latching solenoid, water	22	0.50	300	2.0	44.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, hydrogen	19	0.25	300	2.0	38.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, hydrogen	21	0.25	3000	2.0	42.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, oxygen	19	0.25	300	2.0	38.0	Max flowrate = 0.100 lbm/sec
Valve, latching solenoid, oxygen	21	0.25	3000	2.0	42.0	Max flowrate = 0.100 lbm/sec
Valve, torque motor, hydrogen	8	0.75	300 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
Valve, torque motor, oxygen	8	0.75	300 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
*Valve, vent/relief, nitrogen	8	0.50	300 setpoint	2.0	16.0	Pressurant disposal valve
Valve, quad. check, water	1	0.50	300	2.0	2.0	Isolates hygiene and potable systems
*Regulator, constant press., nitrogen	8	0.38	3000 in/300 out	3.0	24.0	Pressurant control, shutoff capability req'd
Regulator, constant press., hydrogen	1	0.25	3000 in/300 out	3.0	3.0	Regulates down for EGS systems
Regulator, constant press., oxygen	1	0.25	3000 in/300 out	3.0	3.0	Regulates down for EGS systems
Dryer, hydrogen compatible	8	0.25	300	5.0	40.0	Max water removal = .044 lbm/hr
Dryer, oxygen compatible	8	0.25	300	5.0	40.0	Max water removal = .044 lbm/hr
Electrolysis Unit, SPE or KOH	4	0.25	300	300.0	1200.0	Max electrolysis rate = 2.0 lbm water/hr
Compressor, hydrogen	2	0.25	300 in/3000 out	25.0	50.0	
Compressor, oxygen	2	0.25	300 in/3000 out	25.0	50.0	
Total mass					6498.4	

* One item required per spherical bladder tank
**Except where units are specified

Table 4.1-12b Option 8b Integrated O_2 /H_2 System Component List

Item	Qty.	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure Vessel, pot. water storage	4	19.1 cu.ft.	300	66.6	266.3	Sperical Bladder Tanks
Pressure Vessel, hyg. water storage	4	3.6 cu.ft.	300	14.5	58.0	Sperical Bladder Tanks
Pressure Vessel, hydrogen storage	6	39.7 cu.ft.	3000	522.9	3137.4	Composite tanks; shape not defined
Pressure Vessel, oxygen storage	6	13.8 cu.ft.	3000	184.9	1109.4	Composite tanks; shape not defined
Disconnect, water, halves	3	0.50	300	3.0	9.0	Triple redundant external seal
Disconnect, hydrogen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Disconnect, oxygen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Valve, latching solenoid, water	22	0.50	300	2.0	44.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, hydrogen	19	0.25	300	2.0	38.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, hydrogen	21	0.25	3000	2.0	42.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, oxygen	19	0.25	300	2.0	38.0	Max flowrate = 0.100 lbm/sec
Valve, latching solenoid, oxygen	21	0.25	3000	2.0	42.0	Max flowrate = 0.100 lbm/sec
Valve, torque motor, hydrogen	8	0.75	300 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
Valve, torque motor, oxygen	8	0.75	300 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
*Valve, vent/relief, nitrogen	8	0.50	300 setpoint	2.0	16.0	Pressurant disposal valve
Valve, quad. check, water	1	0.50	300	2.0	2.0	Isolates hygiene and potable systems
*Regulator, constant press., nitrogen	8	0.38	3000 in/300 out	3.0	24.0	Pressurant control, shutoff capability req'd
Regulator, constant press., hydrogen	1	0.25	3000 in/300 out	3.0	3.0	Regulates down for EGS systems
Regulator, constant press., oxygen	1	0.25	3000 in/300 out	3.0	3.0	Regulates down for EGS systems
Dryer, hydrogen compatible	8	0.25	300	5.0	40.0	Max water removal = .044 lbm/hr
Dryer, oxygen compatible	8	0.25	300	5.0	40.0	Max water removal = .044 lbm/hr
Electrolysis Unit, SPE or KOH	4	0.25	300	300.0	1200.0	Max electrolysis rate = 2.0 lbm water/hr
Compressor, hydrogen	2	0.25	300 in/3000 out	25.0	50.0	
Compressor, oxygen	2	0.25	300 in/3000 out	25.0	50.0	
Total mass					6313.1	

* One item required per spherical bladder tank
**Except where units are specified

Table 4.1-12c Option 8c Integrated O_2 /H_2 System Component List

Item	Qty.	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure Vessel, pot. water storage	4	16.9 cu.ft.	300	59.5	237.9	Sperical Bladder Tanks
Pressure Vessel, hyg. water storage	4	3.6 cu.ft.	300	14.4	57.6	Sperical Bladder Tanks
Pressure Vessel, hydrogen storage	6	35.1 cu.ft.	3000	463.7	2782.2	Composite tanks; shape not defined
Pressure Vessel, oxygen storage	6	12.2 cu.ft.	3000	164.4	986.4	Composite tanks; shape not defined
Disconnect, water, halves	3	0.50	300	3.0	9.0	Triple redundant external seal
Disconnect, hydrogen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Disconnect, oxygen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Valve, latching solenoid, water	22	0.50	300	2.0	44.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, hydrogen	19	0.25	300	2.0	38.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, hydrogen	21	0.25	3000	2.0	42.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, oxygen	19	0.25	300	2.0	38.0	Max flowrate = 0.100 lbm/sec
Valve, latching solenoid, oxygen	21	0.25	3000	2.0	42.0	Max flowrate = 0.100 lbm/sec
Valve, torque motor, hydrogen	8	0.75	300 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
Valve, torque motor, oxygen	8	0.75	300 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
*Valve, vent/relief, nitrogen	8	0.50	300 setpoint	2.0	16.0	Pressurant disposal valve
Valve, quad. check, water	1	0.50	300	2.0	2.0	Isolates hygiene and potable systems
*Regulator, constant press., nitrogen	8	0.38	3000 in/300 out	3.0	24.0	Pressurant control, shutoff capability req'd
Regulator, constant press., hydrogen	1	0.25	3000 in/300 out	3.0	3.0	Regulates down for EGS systems
Regulator, constant press., oxygen	1	0.25	3000 in/300 out	3.0	3.0	Regulates down for EGS systems
Dryer, hydrogen compatible	8	0.25	300	5.0	40.0	Max water removal = .044 lbm/hr
Dryer, oxygen compatible	8	0.25	300	5.0	40.0	Max water removal = .044 lbm/hr
Resistojet Assembly	1	0.25	30	41.8	41.8	Includes disconnects, valves, and thrusters
Electrolysis Unit, SPE or KOH	4	0.25	300	300.0	1200.0	Max electrolysis rate = 2.0 lbm water/hr
Compressor, hydrogen	2	0.25	300 in/3000 out	25.0	50.0	
Compressor, oxygen	2	0.25	300 in/3000 out	25.0	50.0	
Total mass					5847.9	

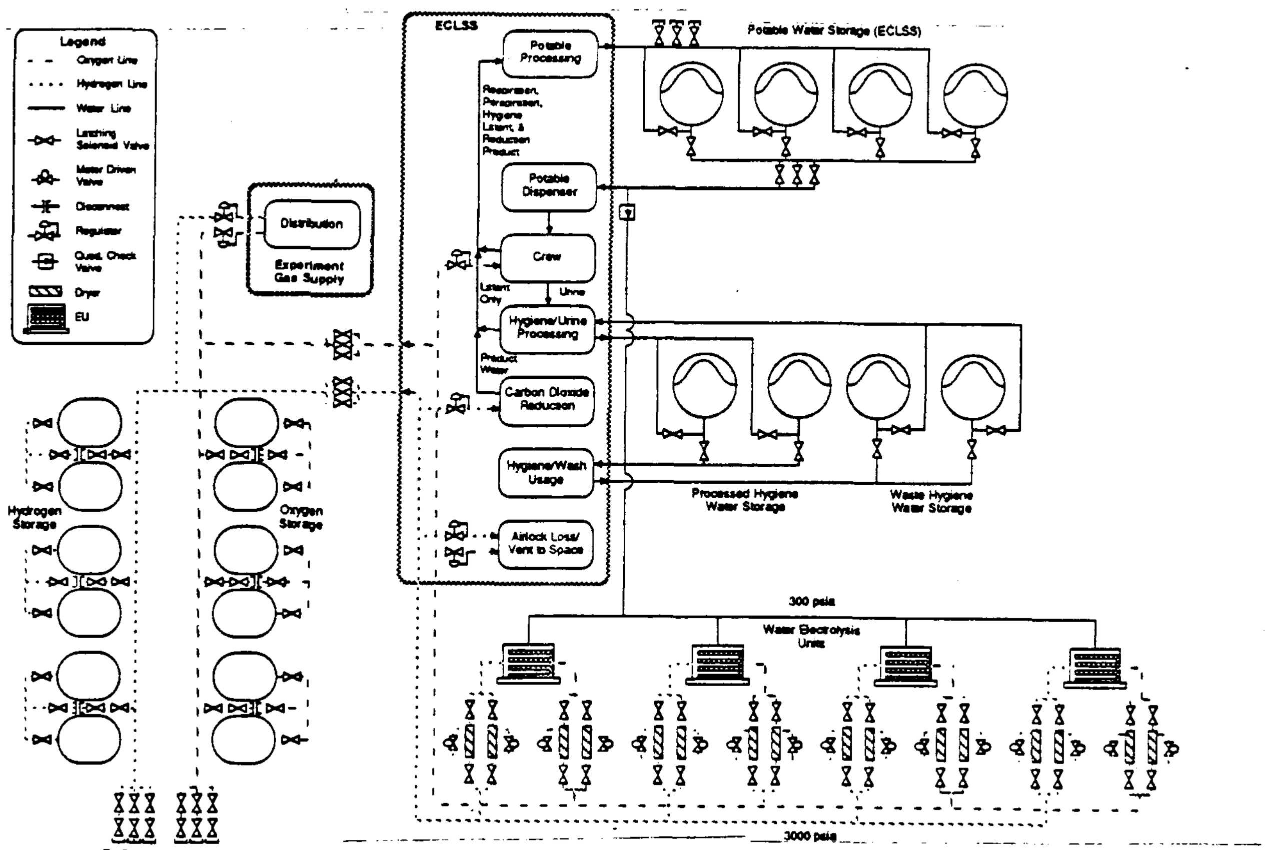

Figure 4.1-9 Option 9 - Fully Integrated O_2 /H_2 System with Pumping Electrolysis Units

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Table 4.1-13a Option 9a Integrated O_2 /H_2 System Component List

Item	Qty.	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure Vessel, pot. water storage	4	14.7 cu.ft.	300	52.3	209.2	Sperical Bladder Tanks
Pressure Vessel, hyg. water storage	4	3.6 cu.ft.	300	14.5	58.0	Sperical Bladder Tanks
Pressure Vessel, hydrogen storage	6	42.2 cu.ft.	3000	554.5	3327.0	Composite tanks; shape not defined
Pressure Vessel, oxygen storage	6	14.5 cu.ft.	3000	193.7	1162.2	Composite tanks; shape not defined
Disconnect, water, halves	3	0.50	300	3.0	9.0	Triple redundant external seal
Disconnect, hydrogen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Disconnect, oxygen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Valve, quad. check, water	1	0.50	300	2.0	2.0	Isolates hygiene and potable systems
Valve, latching solenoid, water	22	0.50	300	2.0	44.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, hydrogen	40	0.25	3000	2.0	80.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, oxygen	40	0.25	3000	2.0	80.0	Max flowrate = 0.100 lbm/sec
Valve, torque motor, hydrogen	8	0.75	3000 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
Valve, torque motor, oxygen	8	0.75	3000 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
*Valve, vent/relief, nitrogen	8	0.50	300 setpoint	2.0	16.0	Pressurant disposal valve
*Regulator, constant press., nitrogen	8	0.38	3000 in/300 out	3.0	24.0	Pressurant control, shutoff capability req'd
Regulator, constant press., hydrogen	3	0.25	3000 in/300 out	3.0	9.0	Regulates down for ECLS & EGS systems
Regulator, constant press., oxygen	3	0.25	3000 in/300 out	3.0	9.0	Regulates down for ECLS & EGS systems
Dryer, hydrogen compatible	8	0.25	3000	5.0	40.0	Max water removal = .044 lbm/hr
Dryer, oxygen compatible	8	0.25	3000	5.0	40.0	Max water removal = .044 lbm/hr
Electrolysis Unit, SPE, hyd. pump	4	0.25	3000	300.0	1200.0	Max electrolysis rate = 2.0 lbm water/hr
Total mass					6410.4	

* One item required per spherical bladder tank
**Except where units are specified

Table 4.1-13b Option 9b Integrated O_2 /H_2 System Component List

Item	Qty.	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure Vessel, pot. water storage	4	19.1 cu.ft.	300	52.3	209.2	Sperical Bladder Tanks
Pressure Vessel, hyg. water storage	4	3.6 cu.ft.	300	14.5	58.0	Sperical Bladder Tanks
Pressure Vessel, hydrogen storage	6	39.7 cu.ft.	3000	522.9	3137.4	Composite tanks; shape not defined
Pressure Vessel, oxygen storage	6	13.8 cu.ft.	3000	184.9	1109.4	Composite tanks; shape not defined
Disconnect, water, halves	3	0.50	300	3.0	9.0	Triple redundant external seal
Disconnect, hydrogen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Disconnect, oxygen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Valve, quad. check, water	1	0.50	300	2.0	2.0	Isolates hygiene and potable systems
Valve, latching solenoid, water	22	0.50	300	2.0	44.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, hydrogen	40	0.25	3000	2.0	80.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, oxygen	40	0.25	3000	2.0	80.0	Max flowrate = 0.100 lbm/sec
Valve, torque motor, hydrogen	8	0.75	3000 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
Valve, torque motor, oxygen	8	0.75	3000 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
*Valve, vent/relief, nitrogen	8	0.50	300 setpoint	2.0	16.0	Pressurant disposal valve
*Regulator, constant press., nitrogen	8	0.38	3000 in/300 out	3.0	24.0	Pressurant control, shutoff capability req'd
Regulator, constant press., hydrogen	3	0.25	3000 in/300 out	3.0	9.0	Regulates down for ECLS & EGS systems
Regulator, constant press., oxygen	3	0.25	3000 in/300 out	3.0	9.0	Regulates down for ECLS & EGS systems
Dryer, hydrogen compatible	8	0.25	3000	5.0	40.0	Max water removal = .044 lbm/hr
Dryer, oxygen compatible	8	0.25	3000	5.0	40.0	Max water removal = .044 lbm/hr
Electrolysis Unit, SPE, hyd. pump	4	0.25	3000	300.0	1200.0	Max electrolysis rate = 2.0 lbm water/hr
Total mass					6168.0	

* One item required per spherical bladder tank
**Except where units are specified

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Table 4.1-13c Option 9c Integrated O_2/H_2 System Component List

Item	Qty.	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure Vessel, pot. water storage	4	16.9 cu.ft.	300	52.3	209.2	Sperical Bladder Tanks
Pressure Vessel, hyg. water storage	4	3.6 cu.ft.	300	14.5	58.0	Sperical Bladder Tanks
Pressure Vessel, hydrogen storage	6	35.1 cu.ft.	3000	463.7	2782.2	Composite tanks; shape not defined
Pressure Vessel, oxygen storage	6	12.2 cu.ft.	3000	164.4	986.4	Composite tanks; shape not defined
Disconnect, water, halves	3	0.50	300	3.0	9.0	Triple redundant external seal
Disconnect, hydrogen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Disconnect, oxygen, halves	9	0.25	3000	2.5	22.5	Required for buildup ops
Valve, quad. check, water	1	0.50	300	2.0	2.0	Isolates hygiene and potable systems
Valve, latching solenoid, water	22	0.50	300	2.0	44.0	Max flowrate = 0.67 cu. ft./min
Valve, latching solenoid, hydrogen	40	0.25	3000	2.0	80.0	Max flowrate = 0.020 lbm/sec
Valve, latching solenoid, oxygen	40	0.25	3000	2.0	80.0	Max flowrate = 0.100 lbm/sec
Valve, torque motor, hydrogen	8	0.75	3000 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
Valve, torque motor, oxygen	8	0.75	3000 to vacuum	3.5	28.0	Large flow area req'd for vacuum pumping
*Valve, vent/relief, nitrogen	8	0.50	300 setpoint	2.0	16.0	Pressurant disposal valve
*Regulator, constant press., nitrogen	8	0.38	3000 in/300 out	3.0	24.0	Pressurant control, shutoff capability req'd
Regulator, constant press., hydrogen	3	0.25	3000 in/300 out	3.0	9.0	Regulates down for ECLS & EGS systems
Regulator, constant press., oxygen	3	0.25	3000 in/300 out	3.0	9.0	Regulates down for ECLS & EGS systems
Dryer, hydrogen compatible	8	0.25	3000	5.0	40.0	Max water removal = .044 lbm/hr
Dryer, oxygen compatible	8	0.25	3000	5.0	40.0	Max water removal = .044 lbm/hr
Resistojet Assembly	1	0.25	30	41.8	41.8	Includes disconnects, valves, and thrusters
Electrolysis Unit, SPE, hyd. pump	4	0.25	3000	300.0	1200.0	Max electrolysis rate = 2.0 lbm water/hr
Total mass					5731.6	

* One item required per spherical bladder tank
**Except where units are specified

4.2 COST ASSESSMENT OF THE INTEGRATED OXYGEN/HYDROGEN SYSTEM

The Integrated Cost Model which was developed in Task I of this program for propulsion systems was used to evaluate the Integrated O_2/H_2 System concepts described above. This cost model analysis included costs for initial hardware, spare parts, launch, maintenance, fluid resupply, and waste deorbit. The cost model software includes cababilities for calculating software and assembly costs, but these were omitted due to the uncertainty of the quantity of each required. These omissions were assumed to make little or no difference between the candidates due to the similarities in the systems. The only case where inconsistencies in the evaluation may have occured due to these omissions was in the ground assembly costs; however, these costs were still assumed to be insignificant due to their relatively low cost.

Costs were analyzed using the parts lists and resupply/disposal masses discussed in Section 4.1. Twenty-four combinations were identified as shown in the Schematic (Option) column of Table 4.1-2. The cost model was run for each of these combinations. The results of the cost model comparison are shown in Table 4.2-1, including initial, operating, life cycle (initial plus operating), and relative cost. The baseline for the relative costs was Option 2a, the reference system identified in Section 4.1.1.2. Option 2a is a partially integrated system which integrates fluids only by piping excess water from the ECLSS to the propulsion system.

Life Cycle Cost (LCC) was the basis on which this study determined the optimum O_2/H_2 system configuration. The two costs which contribute to Life Cycle Cost are Initial Operating Configuration (IOC) cost and Operating cost. IOC Cost includes hardware costs with wraparounds, launch costs, and assembly costs. Operating cost includes spare parts and propellant resupply costs along with associated launch costs, maintenance costs, and waste de-orbit costs. As can be seen in Table 4.2-1, the major contributor to LCC is Operating cost.

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Table 4.2-1 Results of the Cost Compasrison for 24 Integrated O_2/H_2 Systems

Option Number	IOC Cost	Operating Cost	Life Cycle Cost	% of Baseline LCC Cost
1a	134.40	771.53	905.93	130.0%
1b	134.40	627.40	761.80	109.3%
2a	135.03	562.00	697.03	100.0%
2b	135.23	567.09	702.32	100.8%
2c	155.74	518.28	674.02	96.7%
3	141.14	534.73	675.87	97.0%
4a	112.40	524.26	636.66	91.3%
4b	112.21	557.73	669.94	96.1%
4c	132.53	508.83	641.36	92.0%
5a	113.53	521.60	635.13	91.1%
5b	113.33	555.07	668.40	95.9%
5c	133.65	506.18	639.83	91.8%
6a	105.96	521.75	627.71	90.1%
6b	105.77	555.22	660.99	94.8%
6c	126.09	506.32	632.41	90.7%
7a	103.73	457.82	561.55	80.6%
7b	103.01	492.53	595.54	85.4%
7c	123.41	443.05	566.46	81.3%
8a	107.35	456.82	564.17	80.9%
8b	106.63	490.76	597.39	85.7%
8c	127.04	442.05	569.09	81.6%
9a	99.75	455.31	555.06	79.6%
9b	99.03	489.25	588.28	84.4%
9c	119.43	440.54	559.97	80.3%

4.2.1 Effect of Integration Level on Life Cycle Cost

The graphs in Figures 4.2-1 through 4.1-5 show the effect the amount of integration has on the cost of constructing, building, and using systems to perform ECLS, Propulsion, and Gas Supply functions on the Space Station. These three figures show how integration affects costs for systems using the three carbon dioxide reduction schemes, Bosch, Sabatier, and Sabatier using waste CO_2/CH_4 in resistojets. The cost savings realized from increasing the level of integration must be examined seperately for IOC and Operating costs.

IOC cost reflects the level of hardware integration that has been achieved. As can be seen in Figure 4.2-1, Options 1a, 2a, and 3 have approximately the same IOC cost , then there is a drop between them and Options 4a, 5a, and 6a. This drop reflects the reduction in the total number of electrolysis units and water storage tanks required. A smaller level of savings is realized for Options 7a, 8a, and 9a because of the elimination of seperate gas storage tanks. These savings are not associated with the operating characteristics of the system and therefore do not fall along the lines of the Non-Integrated, Partially Integrated, and Fully Integrated breakdown. Simiar effects are seen for systems using the other CO_2 reduction schemes and are shown in Figures 4.2-4 and 4.2-5.

The level of fluids integration achieved is reflected in the Operating cost. The graph in Figure 4.2-2 shows the great cost savings obtained by sharing the excess water from the ECLS with the Propulsion system. This is a direct result of both the reduction in total water quantity that must be

(*Text continued on page 28*)

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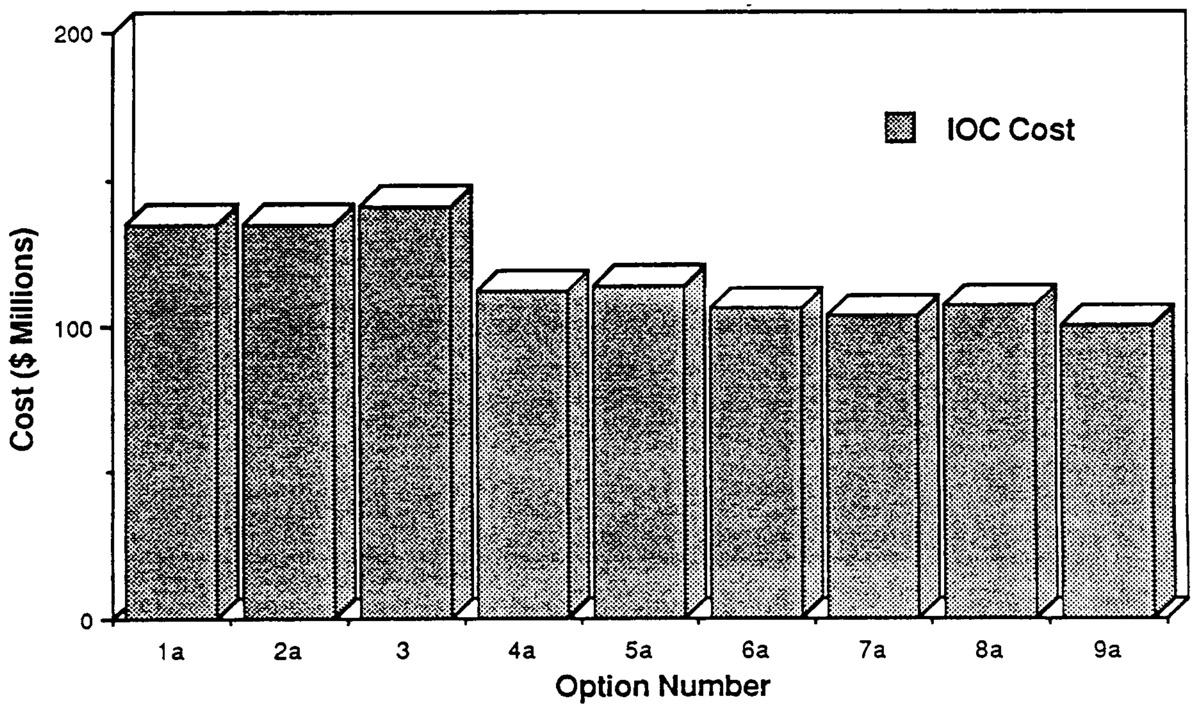

Figure 4.2-1 IOC Cost for Bosch Systems

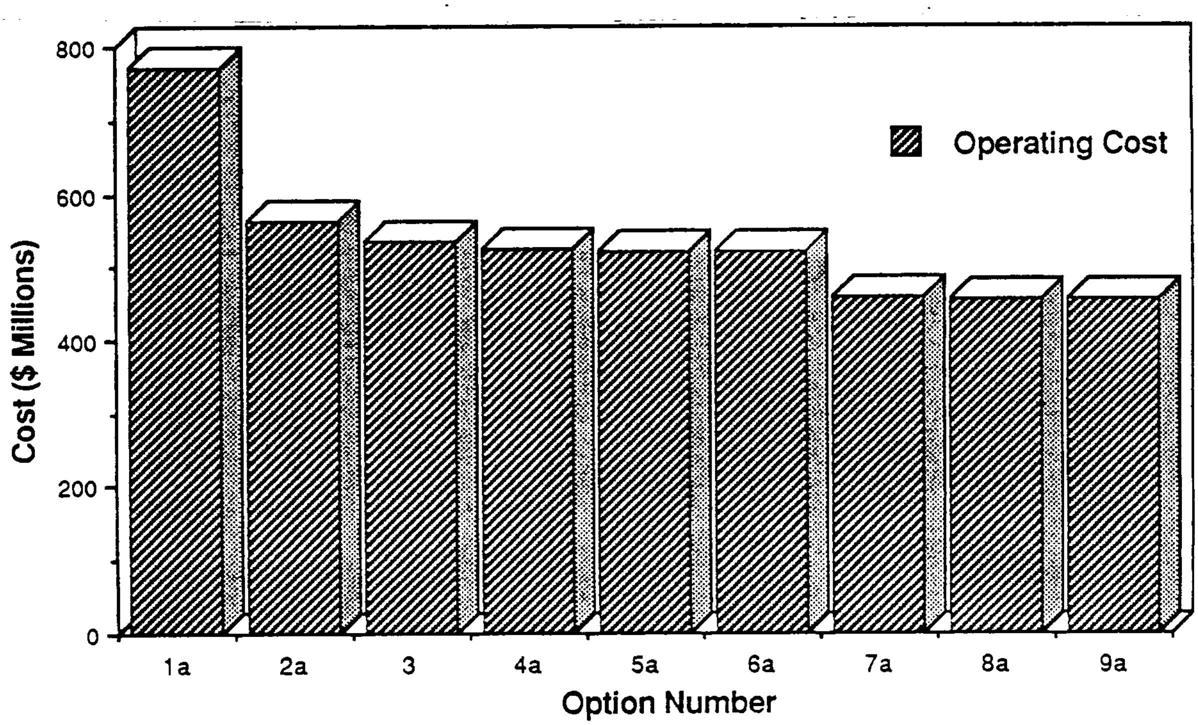

Figure 4.2-2 Operating Cost for Bosch Systems

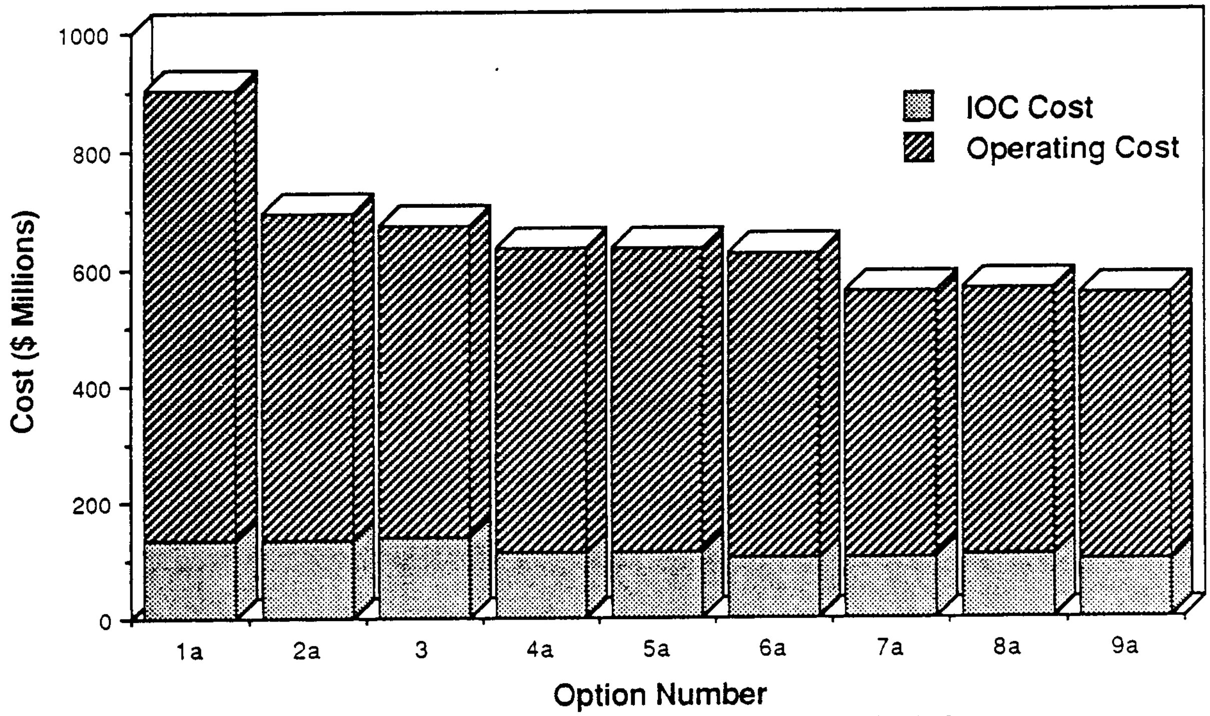

Figure 4.2-3 LCC Cost for Bosch Systems

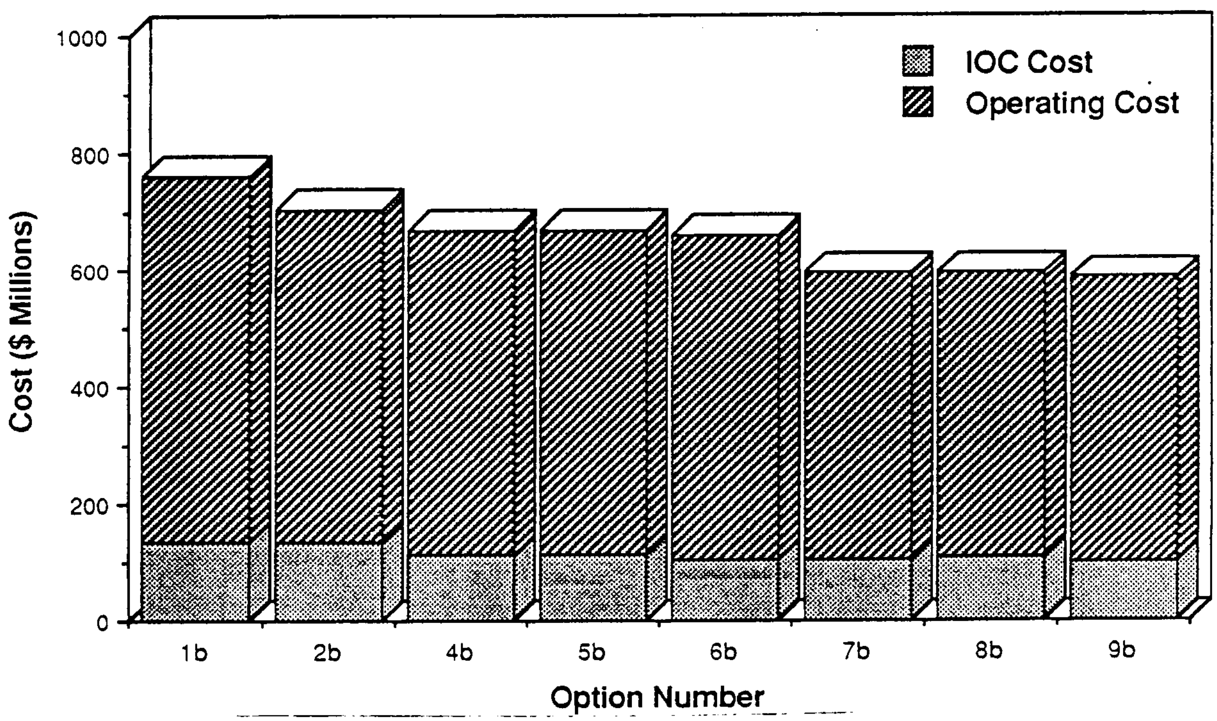

Figure 4.2-4 LCC Cost for Sabatier Systems

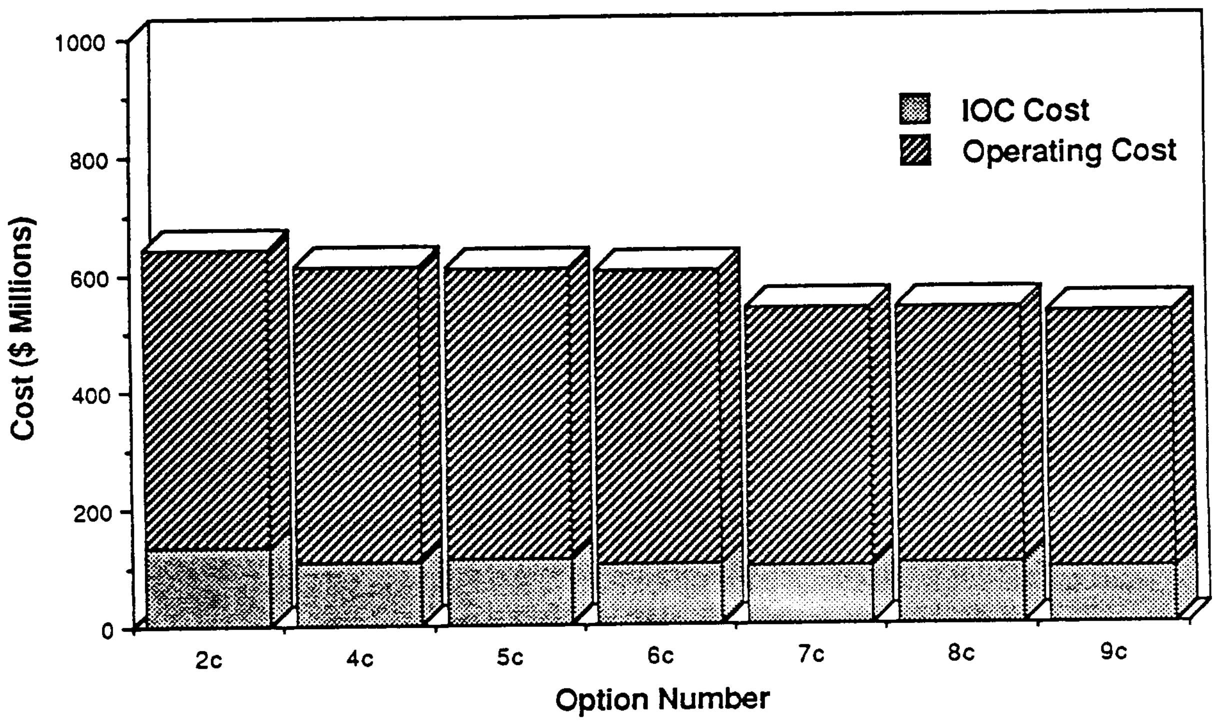

Figure 4.2-5 LCC Cost for Sabatier with Resistojets Systems

delivered to the Space Station, and the elmination of the requirement to deorbit any waster water. This is shown by the step down from Option 1a to Option 2a. The next step down in operating cost is from Option 2a to Option 3, which corresponds to the savings achieved by using waste H_2 from the ECLSS to increase the specific impulse of the propellants for maneuvering. As can be seen in the graph, there is a small step down from Option 3 to Options 4a - 6a. This savings is the result of maintaining less hardware for the latter three systems. The large jump down from Options 4a - 6a to 7a - 9a is the result of using excess hydrogen for propulsion functions. This additional excess H_2 is the byproduct of electrolyzing water to provide oxygen for experiments. The same changes are apparent in Figures 4.2-4 and 4.2-5 for systems using other CO_2 reduction schemes.

Figure 4.2-3 combines the IOC and Operating costs for the Bosch systems to arrive at the Life Cycle Cost. The addition of the two types of costs leads to several combinations, all of which show that as systems become more integrated their costs go down. The same trend is also shown for Life Cycle Costs for both Sabatier and Sabatier with resistojets systems in Figures 4.2-4 and 4.2-5.

4.2.2 Effect of Carbon Dioxide Reduction Process on Life Cycle Cost

Figure 4.2-6 shows the IOC and Operating costs for Options 4a, 4b, and 4c which represent systems using Bosch, Sabatier, and Sabatier with resistojets, respectively. This representative option shows that the costs for an individual option are similar; however, the variations are consistent throughout the different options.

The IOC cost for the Sabatier with resistojets system is higher than those for the Bosch and Sabatier concepts because of the cost that is incurred to install the resistojet system. Otherwise, the three systems are very similar with hardware variations only in the size of the storage tanks.

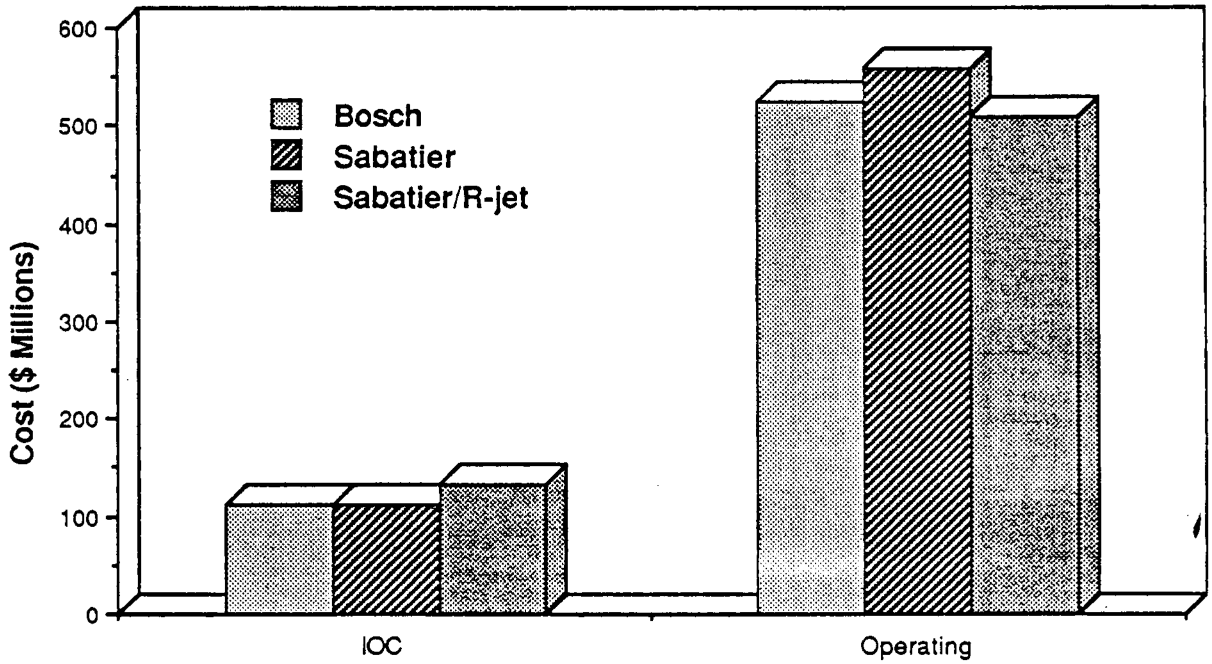

Figure 4.2-6 Comparison of IOC and Operating Costs for the Three Carbon Dioxide Reduction Schemes

The Operating costs for the three types of systems also vary in a fairly consistent manner among the various options. Because the Bosch ECLSS provides excess hydrogen to the propulsion system, the cost of operating it is less than that of the Sabatier, even when taking into account the need for solid carbon to be deorbited when using the Bosch. The use of resistojets to propulsively dispose of waste CO_2/CH_4 from the Sabatier ECLSS provides the savings shown for the Sabatier with resistojets system by decreasing the amount of water that must be supplied for propulsion.

4.2.3 Overall Effects of Integration on Life Cycle Cost

Figure 4.2-7 shows the Life Cycle costs for all 24 options that were analyzed in this study. This graph combines the effects shown prevoiously and displays them in such a way as to demonstrate the optimum system. The optimum system, as shown both graphically in Figure 4.2-7 and numerically in Table 4.2-1 above, is Option 9a, the Fully Integrated Bosch system with a pumping electrolysis unit. However, the cost difference between this system and its closest followers is not large enough to set it apart as the clear "winner," due to the possible errors introduced in the assumptions. Any one change in the assumptions could change the ranking between systems.

The general trend shown in Figure 4.2-7 is that as systems become more integrated, so also do they become less expensive to build and operate. This is in essence the desired outcome from this comparison; the actual results as to the exact configuration of the optimum system are only a byproduct and are so close as to not provide a definite solution.

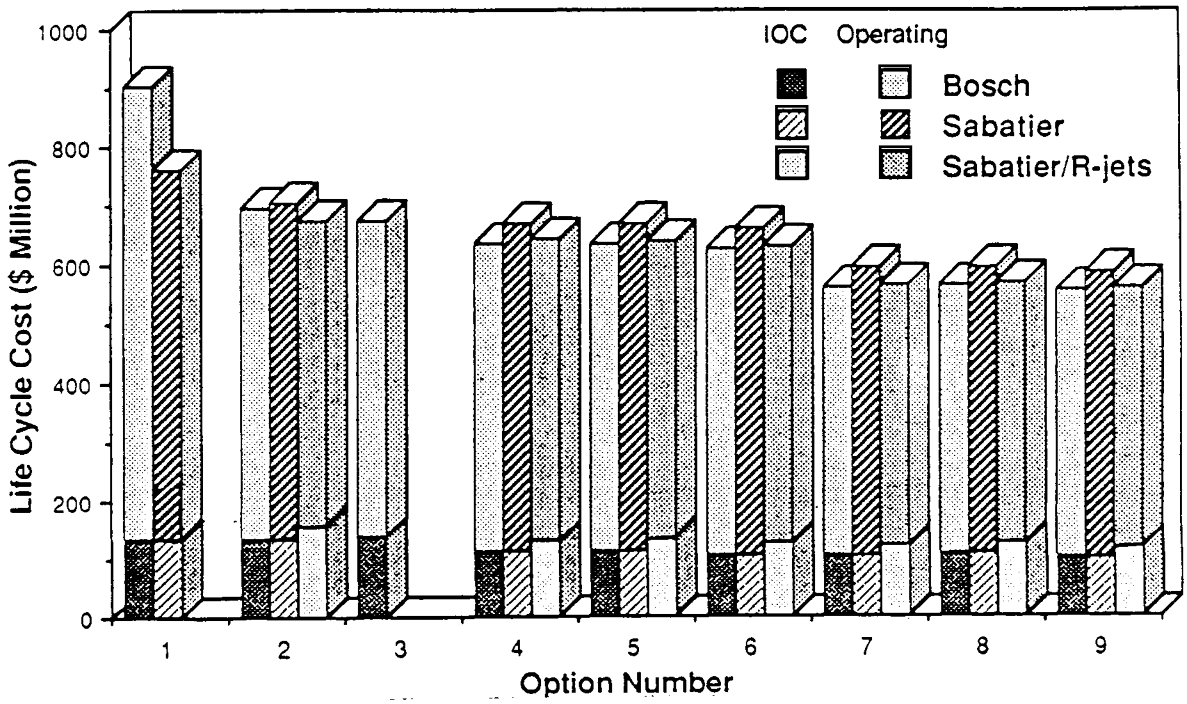

Figure 4.2-7 Effect of Integration on LCC Cost for O_2/H_2 Systems

5.0 INTEGRATED WATER SYSTEM

A system level investigation of an Integrated Water System (IWS) was performed to evaluate the benefits of such a concept. Tasks required to define the system included 1) an investigation into the National Space Transportation System (NSTS) Shuttle potable water generation and the availability of this water for transfer to the Space Station, 2) definition and evaluation of potable water storage concepts for the Space Station, 3) identification of water resupply requirements and evaluation of concepts for meeting these requirements, and 4) definition of Space Station water distribution options. Discusions of water quality monitoring and decontamination issues are included in Appendices A and B, respectively.

5.0.1 Water Sensitivity Analysis

A water sensitivity analysis was conducted at the beginning of the study to define the relative importance of the factors which effect the amount of water on the station and its distribution. Parameters investigated in this analysis include the following:

1) Bosch CO_2 reduction,
2) Sabatier CO_2 reduction,
3) Interaction of the NSTS crew on board SS,
4) NSTS fuel cell water - availability and quantity,
5) Extra-Vehicular Activity (EVA) water requirements,
6) SS crew food water content,
7) Resupply period,
8) Integration of the Japanese Experiment Module (JEM) and Columbus (COL) water requirements and,
9) United States Laboratory (USL) water requirements.

The sensitivity analysis was conducted using a Microsoft Excell spreadsheet program on a Macintosh Plus personal computer. The spreadsheet format, baseline input parameter values, and baseline water balance are shown in Figure 5.0-1. The spreadsheet inputs that effect the balance

SPACE STATION WATER BALANCE PER 90 DAYS				
INPUTS:		WATER BALANCE,lbs		
Station Crew Size	8	ECLSS Potable	+	737
Water Balance Time Duration , Days	90	STS Potable Water	+	1671
EVAs per balance duration, days	13	Station Potable Water	=	2407
EMU Loop Closure	CLOSED	Station EVA Water	-	0
Orbiter Crew Size	8	Lab Module Requirements	-	1242
Orbiter Crew on Station	4	Excess Water (Propulsion)	=	1165
Orbiter Power Level ,Kw	10			
Orbiter Stay Duration,days	5	STS Waste Water*		288
Orbiter Visits per balance duration	2			
Scavenged Orbiter Storage Tank H20,lbm	0			
Food Water Content,lbm/man/day	1.1			
ECLSS CO2 Reduction Process	BOSCH			
ECLSS H2O Output, Lbm/man-days	0.93			
COL Water Requirement, Lbm/day	0			
JEM Water Requirement, Lbm/day	0			
USL Experiments Requirement ,lbm/day	13.8	*Not included in excess water		
USL Experiment Water Recovery,%	85			

Figure 5.0-1 Water Balance Sensitivity Analysis -- Baseline

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are SS crew size, length of time the orbiter is docked to the SS, the number of orbiter crew members who use the station facilities, orbiter fuel cell average power level while docked, SS crew food water content, the CO_2 reduction process, and laboratory experiment water requirements. The computed results include the quantities of Environmental Control and Life Support System (ECLSS) excess potable water, NSTS generated ultrapure and waste water, and EVA and experiment water requirements. The laboratory water requirements are subtracted from the excess potable water to determine the total excess water available for use in the propulsion system. The ECLSS excess water generation rate was computed using the MACMIMBA computer program[1] with input parameters supplied by Hamilton Standard[2]. The baseline balance gives a total excess water amount of 1165 lbm per 90 days. This study did not take into account the propellant savings associated with using excess hydrogen to augment the propulsion capabilities, nor did it include the benefits of integrating the oxygen and hydrogen requirements of the experiments as described in Section 4.

The sensitivity analysis was carried out by varying each parameter by a consistent amount. The majority of the sensitivity parameters were varied by the same percentage of 25%. This was done in order to observe the effect changing a single parameter had on the total amount of excess water generated, relative to a similar change in each other parameter. In some cases, such as Bosch or Sabatier CO_2 reduction and Advanced Extravehicular Mobility Unit (EMU) or NSTS EMU, this was not possible. In those cases the changes are discrete and cannot be varied by a certain percentage. The result of the sensitivity analysis is seen in Figure 5.0-2. The total excess water generated for each sensitivity parameter is plotted and compared to the baseline. To complement Figure 5.0-2, the percentage change in excess water from baseline for each parameter is shown in Figure 5.0-3. This gives a graphic portrayal of the parameters that effect the water balance. Using the Sabatier CO_2 reduction process the excess water decreases by 45.5%. Increasing the time the shuttle is docked to the SS by 25% increases the amount of excess water by 35%. Integrating the JEM waste water system or increasing the number of NSTS crew on the station has a small effect on the water balance. Alternatively, implementing a 90 day resupply interval has a large

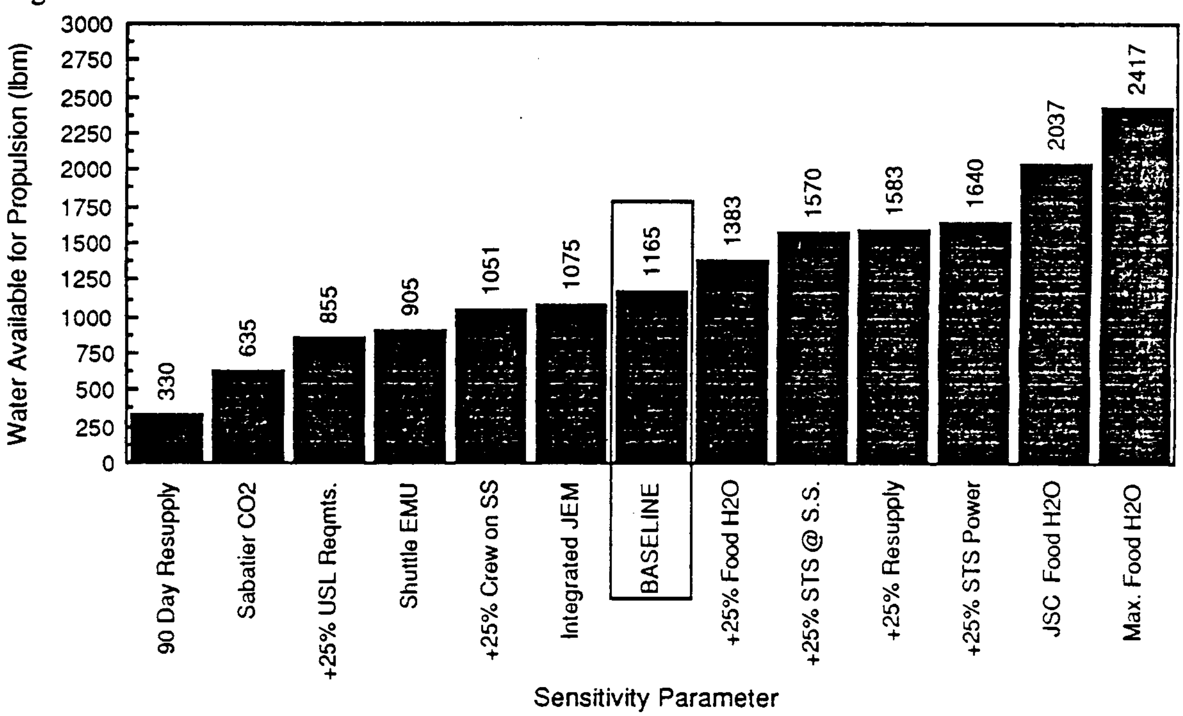

Figure 5.0-2 Water Sensitivity Analysis -- Absolute Scale

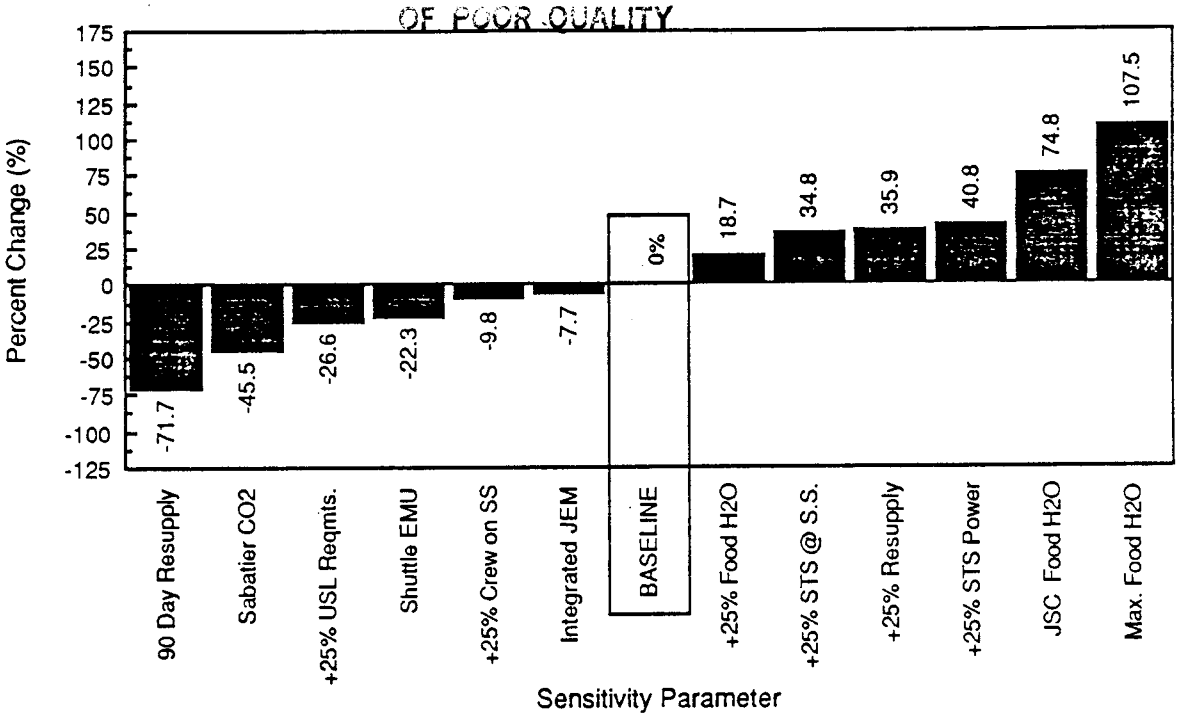

Figure 5.0-3 Water Sensitivity Analysis -- Percent Change from Baseline

negative effect, decreasing the excess water by 72%. The water balance spreadsheets for each sensitivity parameter are presented in Appendix C.

Increasing the water content of the food is an approach for increasing the total excess water at low cost and low technological risk. Increasing the food water content to the Johnson Space Center (JSC) baseline amount of 2.2 lbm/man-day[3], generates 2037 lbm total excess water per 90 days. Increasing the food water content to the maximum content of 2.68 lbms/man-day, as recommended by Al Boehm of Hamilton Standard[2], generates over 2400 lbm excess water. This "maximum" content is the maximum amount of water in a normal diet that is not wasted. An increase of the food water content would also make the food more palatable and simplify cooking procedures. Drawbacks associated with increased food water content are increased food volume and mass, and subsequently larger food storage devices. JSC indicated that the food water content baseline was to be changed from 1.1 to between 2.2 and 3.0 lbm/man-day, so the Hamilton-Standard number concurs with the JSC baseline.

5.1 SHUTTLE ORBITER WATER GENERATION AND AVAILABILITY

The NSTS orbiter fuel cells generate ultrapure (pyrogen-free) water that is available for use on the station. The amount of ultrapure water generated as a function of the NSTS fuel cell power level is shown in Figure 5.1-1[4]. This water is stored in four 165 lbm capacity metal bellows tanks at an operating pressure of 8-17 psi.[5] These tanks are used to store water for use in the fuel cell flash evaporater cooling system. The water available for Space Station use is equal to the amount of water generated by the fuel cells less the amount of water consumed by the astronauts aboard the Shuttle. This amounts to 1671 lbm for a 90 cycle for the reference configuration of 2 orbital visits, with 5 day visit durations, fuel cells powered to 10 kWe and four members aboard the Shuttle. Standard operating procedure while on-orbit is for the fuel cell water to be vented to space; however, when docked to the station the Space Station environmental contamination constraints preclude the venting of this water. The orbiter storage tanks are much too small to store all the water generated during a typical stay at the station, therefore, to meet environmental requirements and to reduce propellant delivery costs, the excess water must be transferred to the station. The water from the shuttle tanks is accessible from the contigency H_2O cross

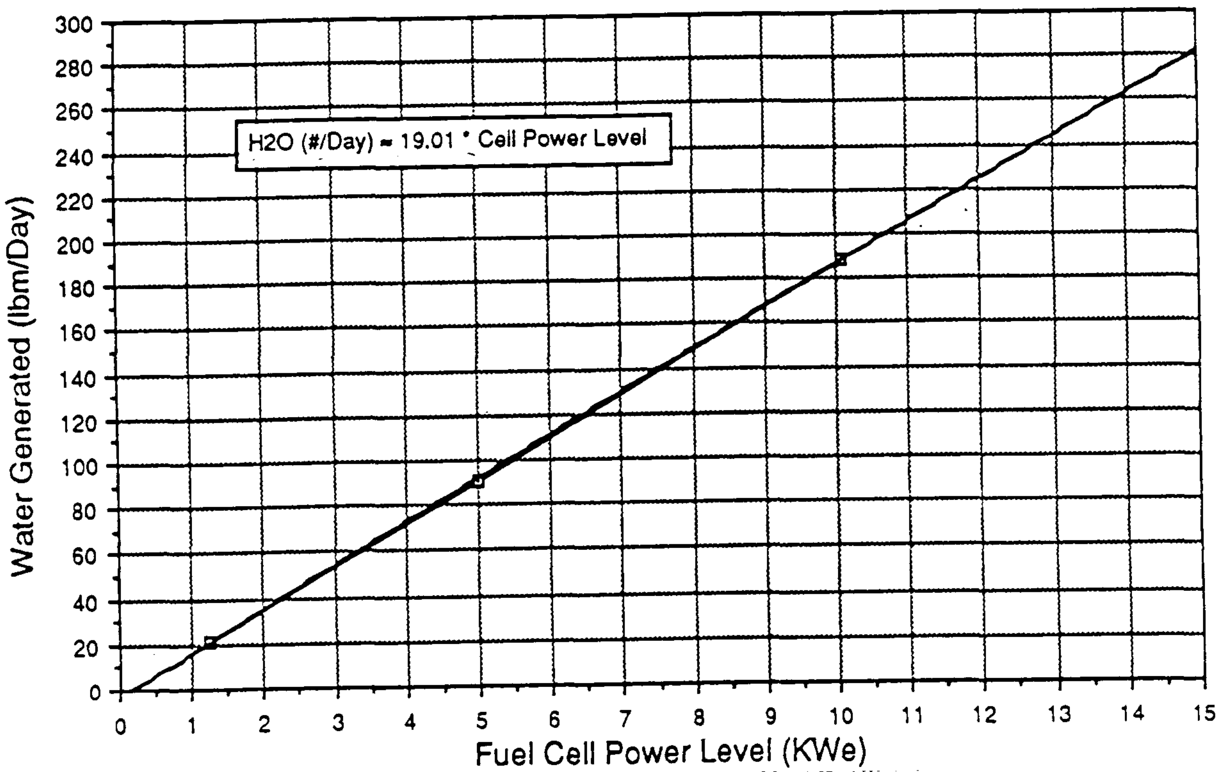

Figure 5.1-1 NSTS Fuel Cell Ultrapure Water Generation Rate

tie in the shuttle mid-deck. A simple flex hose connection between the mid-deck cross-tie and a quick disconnect (QD) located on the potable water line in the node to which the orbiter is docked has been proposed to eliminate permanent hardware. A small portable pump would be required to transfer the water from the shuttle to the station due to the lower operating pressure in the tanks on the orbiter.

The orbiter waste water tank will also fill up during a typical mission. Each shuttle crew member generates about 7.46 lbm of waste water per day. This waste water is stored in a single metal bellows tank identical to the ultrapure tanks and is also periodically vented overboard. As with the ultrapure water, the station venting constraints preclude the venting of the waste water to space, and the amount generated will be too large to store during a typical shuttle stay. No provision for waste fluid transfer from the shuttle to the station ECLSS is anticipated, though, because of the safety concerns of pumping a contaminated fluid across interface connections. The best solution is to require the shuttle crew members to use the station facilities for washing and urinating. Eighty percent of the waste water genterated during a typical shuttle stay will be input into the station ECLSS this way. Respiration and perspiration water will then be the only inputs into the shuttle waste tank.[6]

5.2 PROPELLANT WATER REQUIREMENTS

Excess potable water is electrolyzed and used in the H_2/O_2 thrusters for station altitude reboost. Thus the amount of potable water generated has an effect on the water storage and logistic resupply requirement. The amount of propellent required changes as a function of the atmospheric drag the station encounters. The amount of upper-atmospheric drag is difficult to predict because the upper atmosphere expands and contracts in concert with the solar wind, while the solar wind is a function of the solar activity (sun spots, flares, etc.), and the season (the position of the earth in its elliptical orbit). This expansion and contraction can change the density of the upper-atmosphere by many orders of magnitude in a short period of time. Therefore, because of the uncertainties in the amount of drag, there is uncertainty in the amount of drag-makeup propellent required. Two cases, a "nominal" atmosphere model and a "+2 sigma" atmospheric model[7], have been used to develop propellant requirements for Space Station reboost. The +2 sigma model can be thought of as an upper bound to the average amount of drag the station will encounter.

The amount of water required for reboost must be known in order to size the on board tankage needed. Figures 5.2-1 and 5.2-2 show the variation in reboost propellant between the nominal and +2 sigma cases during the two years prior to IOC and the first year after IOC. Two scenarios have been developed for resupply, one resupplying at 45 day intervals, the other at 90 day intervals. NASA requires storage of 45 days worth of contingency propellent in case of a missed resupply. As can be seen in the two figures the worst case is the 90 day resupply period (giving a 135 day storage requirement) over the dates of 1-1-95 through 4-15-95. During this 135 day period the propellant requirement is about 5000 lbs. The USL requirement can be added to this and the water generated by the ECLS system subtracted to give the amount of water which must be stored. The USL requirement is 1240 lbm/90 days. Only the 90 day requirement is added to the propulsion requirement because it is assumed that if a resupply period is missed the station will go into a slow down mode to save resources, and most, if not all, experiment activity will cease. As a worst case analysis the lower water producing CO_2 reduction process was chosen to size the system. The Sabatier process generates approximately 1457 lbm of water over 135 days. These parameters indicate a total storage requirement of 4783 lbm.

5.3 LOGISTICS ELEMENTS WATER RESUPPLY

Water may be supplied from the ground in order to supplement the amount of water generated by the ECLSS system and scavenged from the shuttle. Water is required for propulsion and experiment use. The impact of the Space Station elements and environment on the amount of water required from logistic resupply was studied. The parameters included the following: the Bosch and Sabatier CO_2 reduction processes, 45 day and 90 day shuttle resupply frequency, nominal and +2 sigma atmosphere models. The food water content was assumed to be 2.68 lbm/man-day. The baseline numbers were used for the rest of the parameters. The results can be seen in Figures 5.3-1 through 5.3-4. These figures show the amount of water which must be launched into orbit via the shuttle during a typical three year period. Figure 5.3-1 shows a scenario in which no logistically supplied water is required. In the case of a 45 day resupply period, Bosch or Sabatier reduction, and a nominal atmosphere, enough excess water is generated and scavenged to provide the total amount required for propulsion, thus no resupply water is required and more productive use can be made of the NSTS payload. In Figure 5.3-4 the opposite is shown. If a 90 day resupply period and the Sabatier CO_2 reduction process is used during a +2 sigma atmosphere, then over 1200 lbm of water will have to be launched to the Space Station on each resupply flight. This issue will not be resolved until a more accurate atmosphere model is developed and the Space Station configuration is finalized.

5.4 ON ORBIT WATER RESUPPLY SYSTEM CONFIGURATONS

As a worst case analysis a logistic resupply requirement was assumed to exist. JSC's Architectual Control Document shows that the PLC will have ECLSS potable water and nitrogen lines running through the module[8]. Therefore it is proposed that the resupply water be sent directly into the potable water line from the resupply tank. Preliminary resupply and transfer systems are shown in Figures 5.4-1 through 5.4-6. Water transfer is conducted through the use of a pressurized diaphram tank. Diaphram tank technology is well developed and would be cheap to develop for use in a man-rated system. The main technology gap is the control of contamination of the potable water by the diaphram material. However, the benign nature of the fluid may reduce the potential

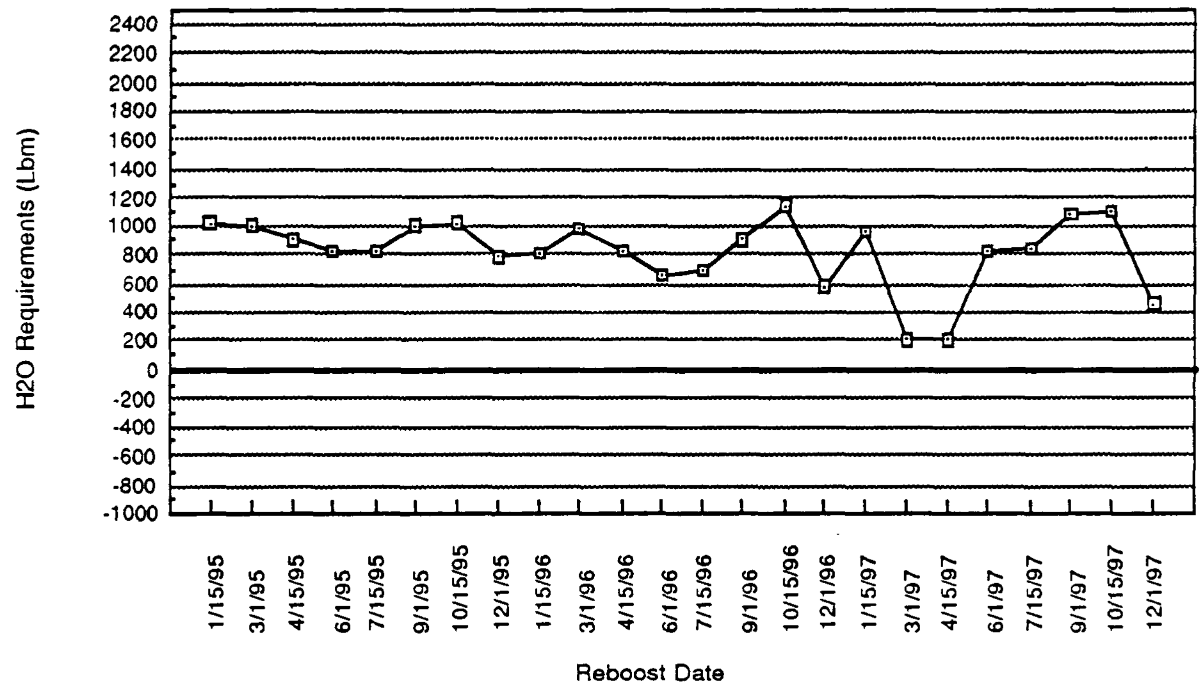

Figure 5.2-1 Typical Reboost Requirements for Nominal Solar Activity

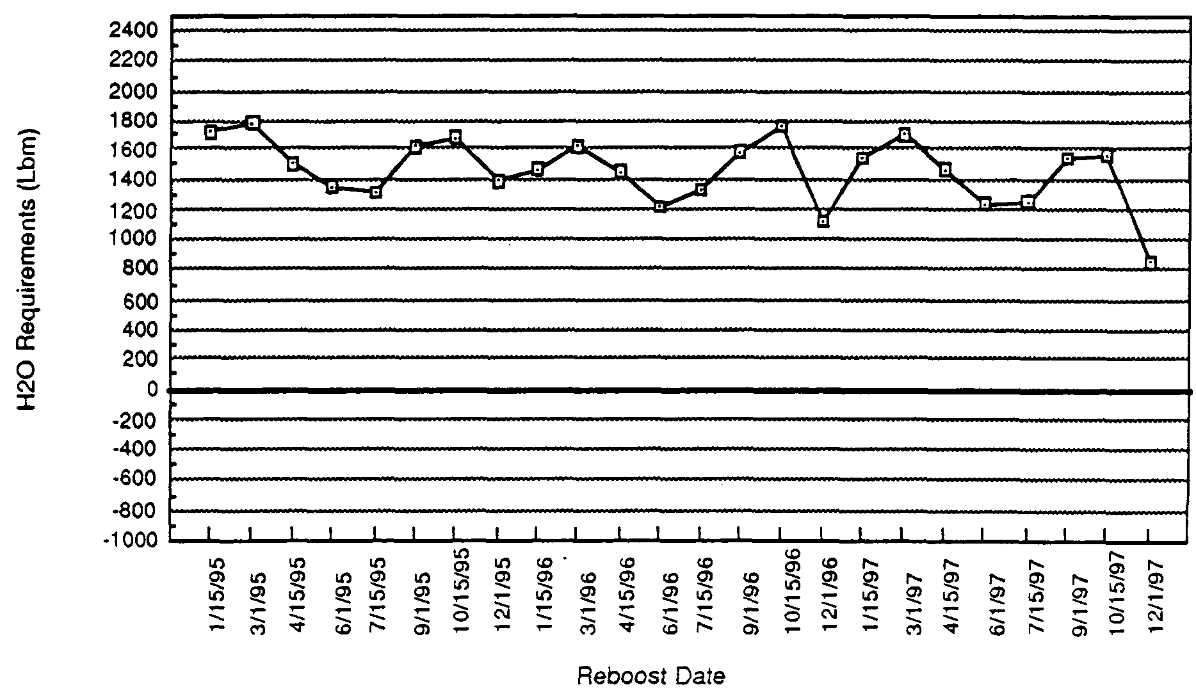

Figure 5.2-2 Typical Reboost Requirements for +2 Sigma Solar Activity

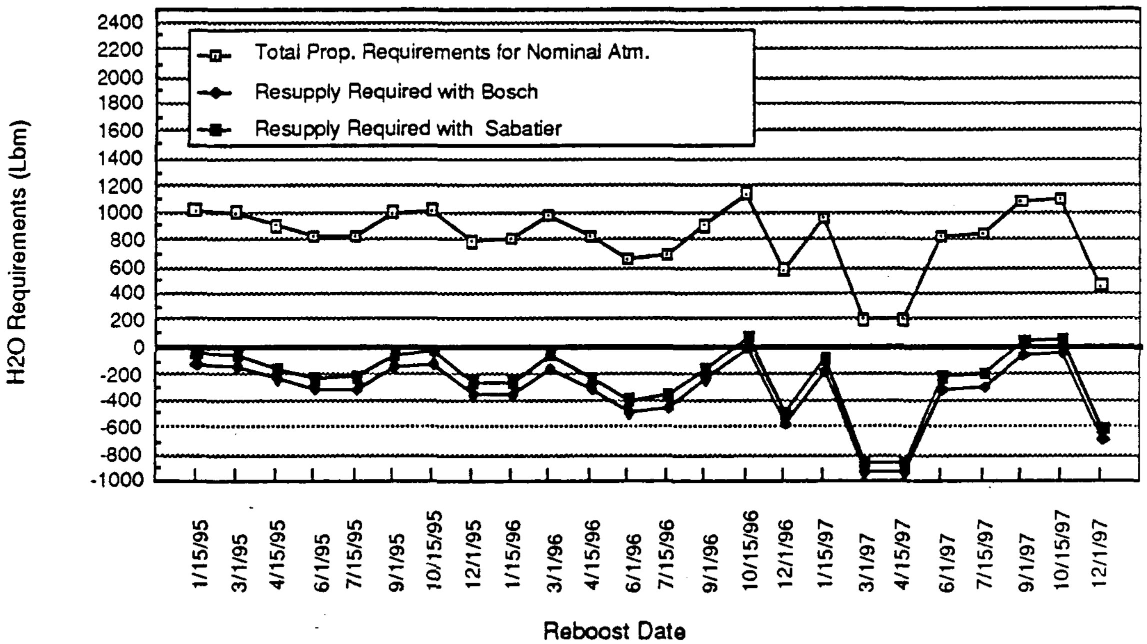

Figure 5.3-1 Typical Water Resupply Requirement for Nominal Solar Activity with 45 Day Resupply Cycle

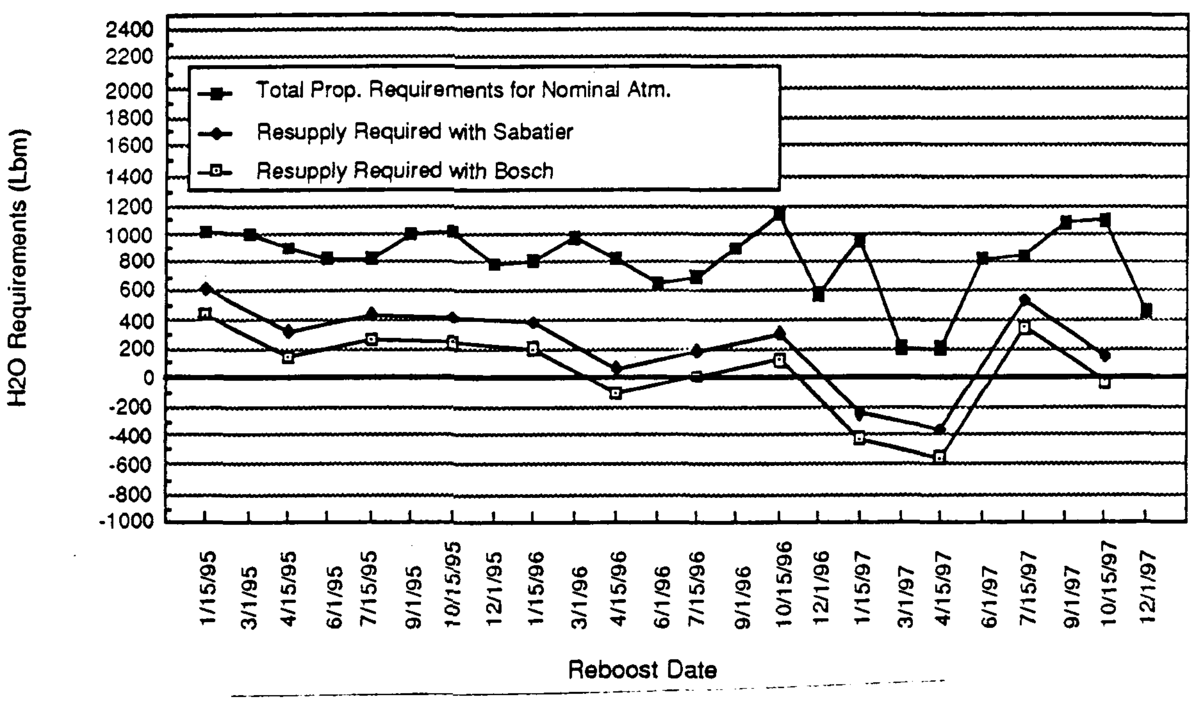

Figure 5.3-2 Typical Water Resupply Requirement for Nominal Solar Activity with 90 Day Resupply Cycle

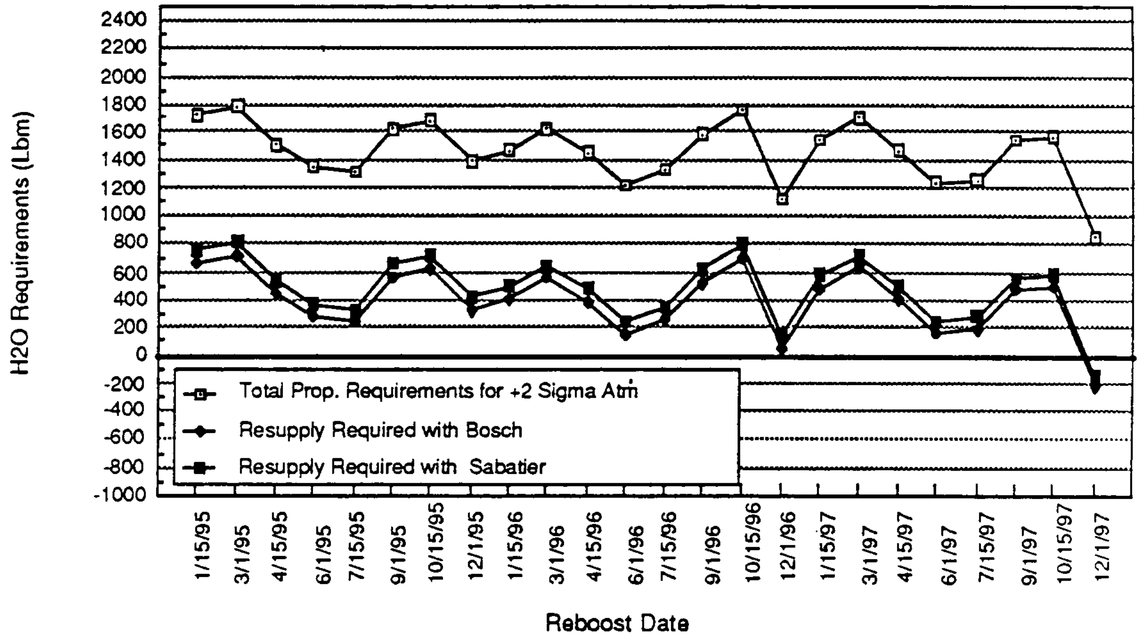

Figure 5.3-3 Typical Water Resupply Requirement for +2 Sigma Solar Activity with 45 Day Resupply Cycle

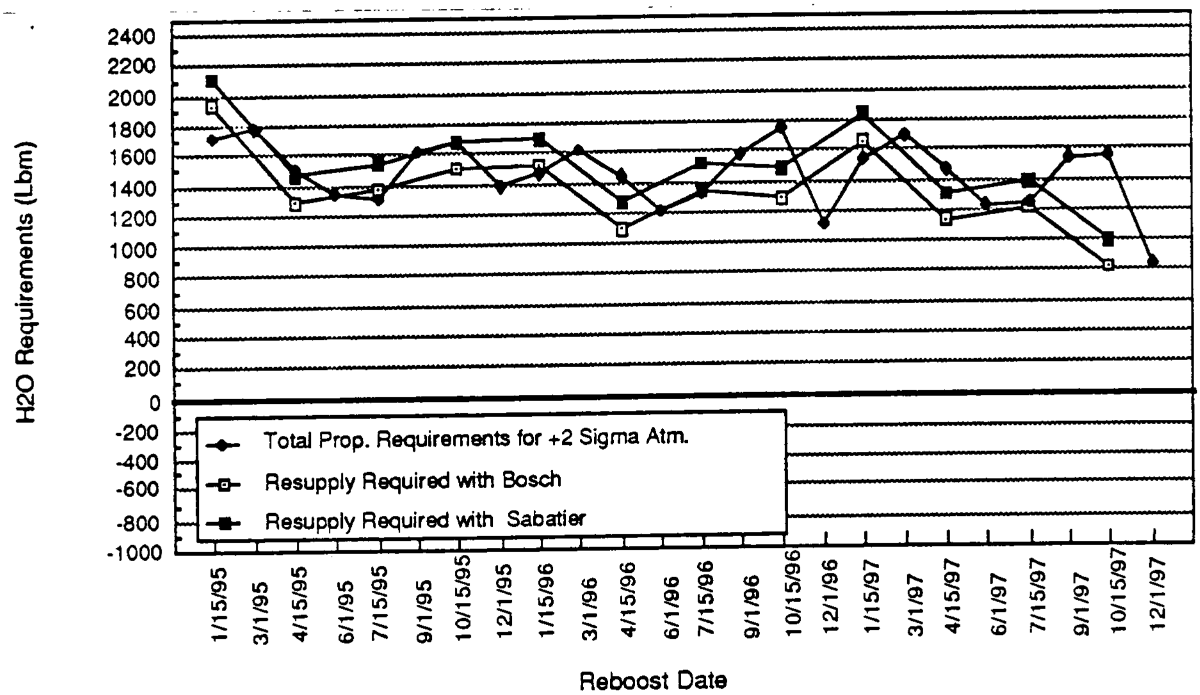

Figure 5.3-4 Typical Water Resupply Requirement for +2 Sigma Solar Activity with 90 Day Resupply Cycle

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materials problems found with hydrazine diaphram tanks. Figures 5.4-1 and 5.4-2 show a proposed water resupply rack where separate pressurant GN_2 bottles are connected to the diaphram tank. The bottles operate in either blowdown (Option 1) or regulated (Option 2) mode. Figure 5.4-3 shows the use of the INS to pressurize the tank via flex lines and QD's (Option 3). Option 4 uses a small portable pump between the PLC and potable tank with a gas bottle providing the necessary net positive suction head (NPSH) for the pump, as shown in Figure 5.4-4. Figure 5.4-5 shows a pressurized ullage in the water tank for providing the NPSH for pumped transfer (Option 5). Finally as shown in Figure 5.4-6, pressurizing the tank ullage to a high enough pressure will force the fluid into the water lines in blowdown operation (Option 6).

Options 1 and 2 incur the hardware cost and weight problems associated with the pressurant bottles. In Option 3, the flex line and valve assemblies that attatch to the N_2 and water lines would be kept on the station, decreasing launch weight. No pressurized ullage would be required, allowing for a greater amount of water to be loaded into the tank. Option 4 has the weight problems and hardware costs of both pressurant bottles and a pump, but the pump decreases the pressurant bottle's pressure. The advantage of operating at a lower pressure is a decrease of the required wall thickness and therefore of the weight of the tanks. The pump could be common with the pump used in transfering the shuttle fuel cell water to the station potable lines. Option 5 has the advantage of requiring only one connection and one flex-line/valve assembly but incurs penalties due to both the larger volume associated with a presurized ullage and the hardware cost of a pump. From the hardware point of view Option 6 is the least expensive method, but the ullage required to pressurize the tank decreases the volume available for water and increases the weight of the tank, which increase launch costs. From this simple analysis option 3 would be the best choice. It uses the resourses provided by the station and components with current technology to facilitate fluid transfer, and incurs the lowest launch costs and lightest tank weight while providing the greatest volume of water per mass of tankage.

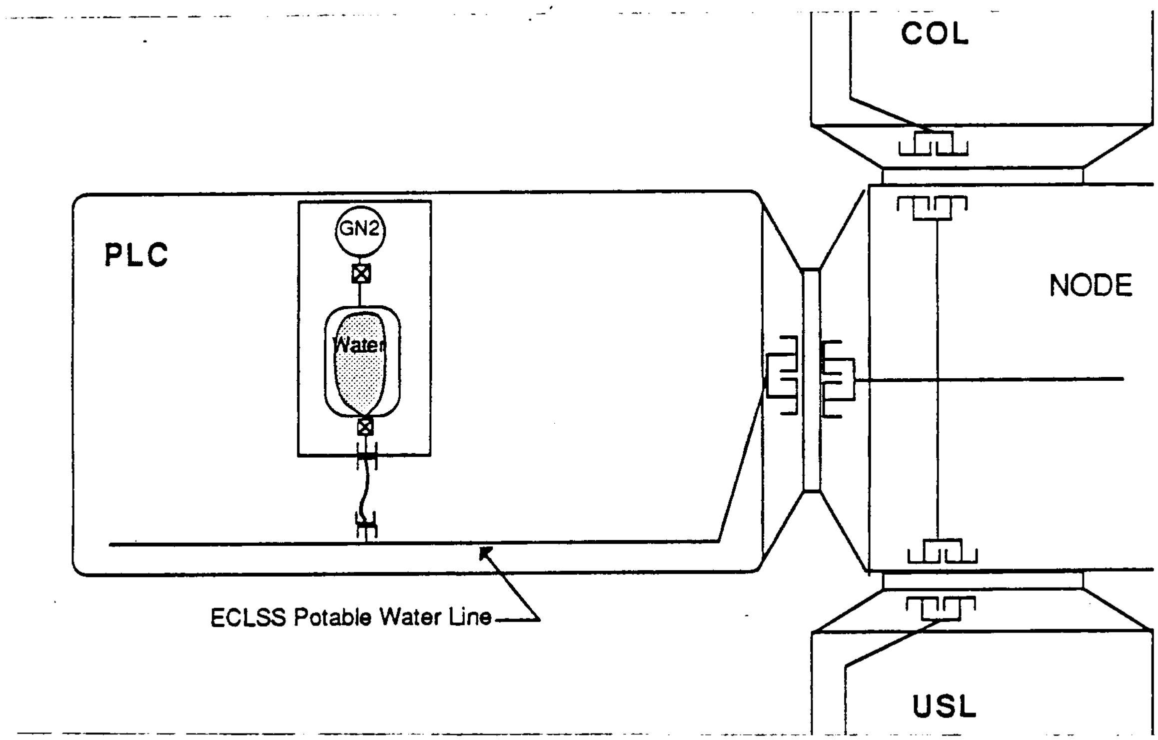

Figure 5.4-1 Option 1 - Water Resupply Tank with Seperate Blowdown Pressurant Tank

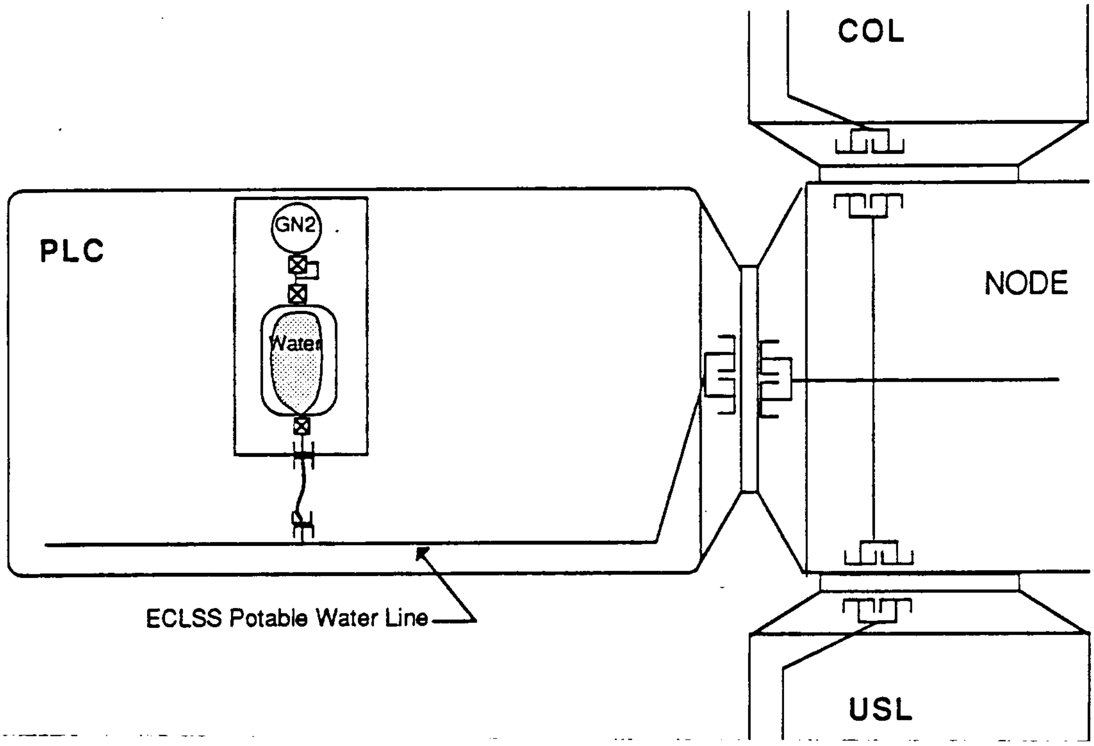

Figure 5.4-2 Option 2 - Water Resupply Tank with Seperate Regulated Pressurant Tank

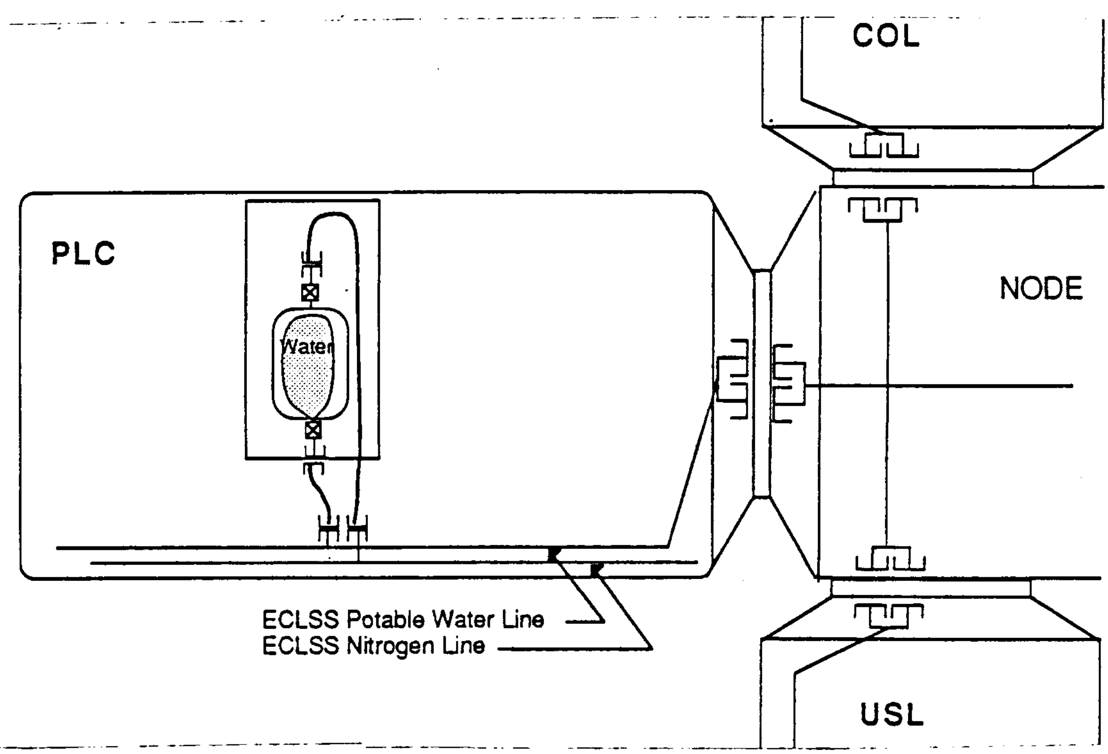

Figure 5.4-3 Option 3 - Water Resupply Tank with Integrated Nitrogen System Pressurization

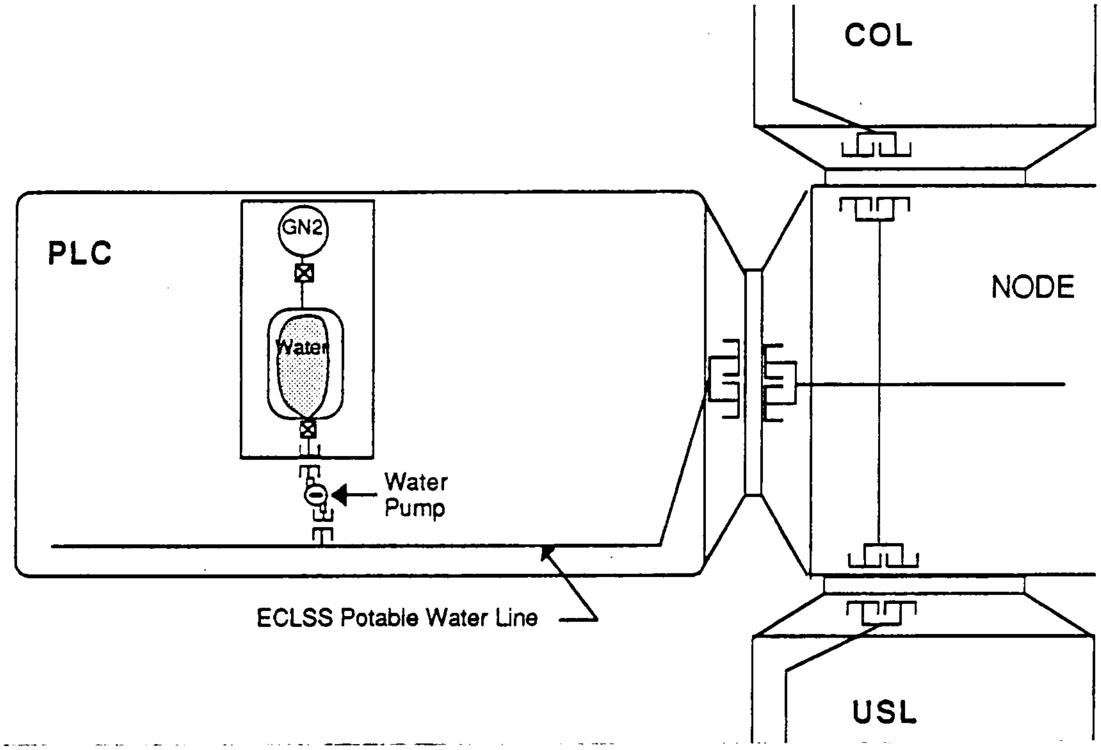

Figure 5.4-4 Option 4 - Water Resupply Tank with Seperate Regulated Pressurant Tank and Portable Pump

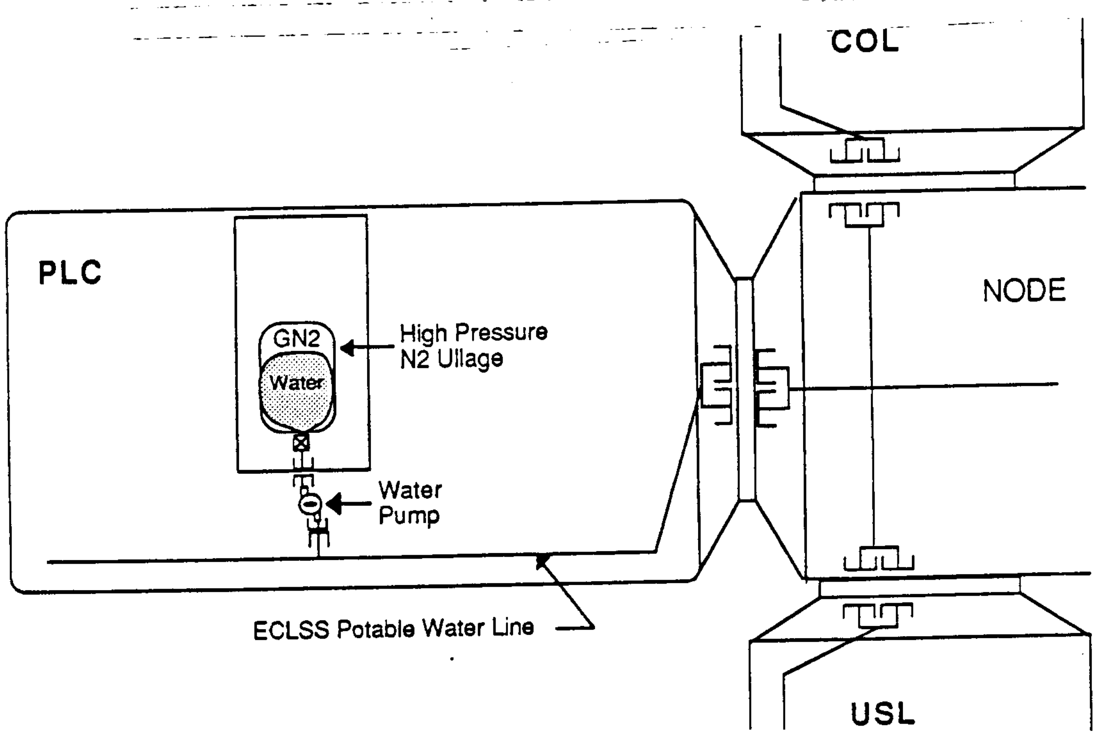

Figure 5.4-5 Option 5 - Water Resupply Tank with Pressurized Ullage and Portable Pump

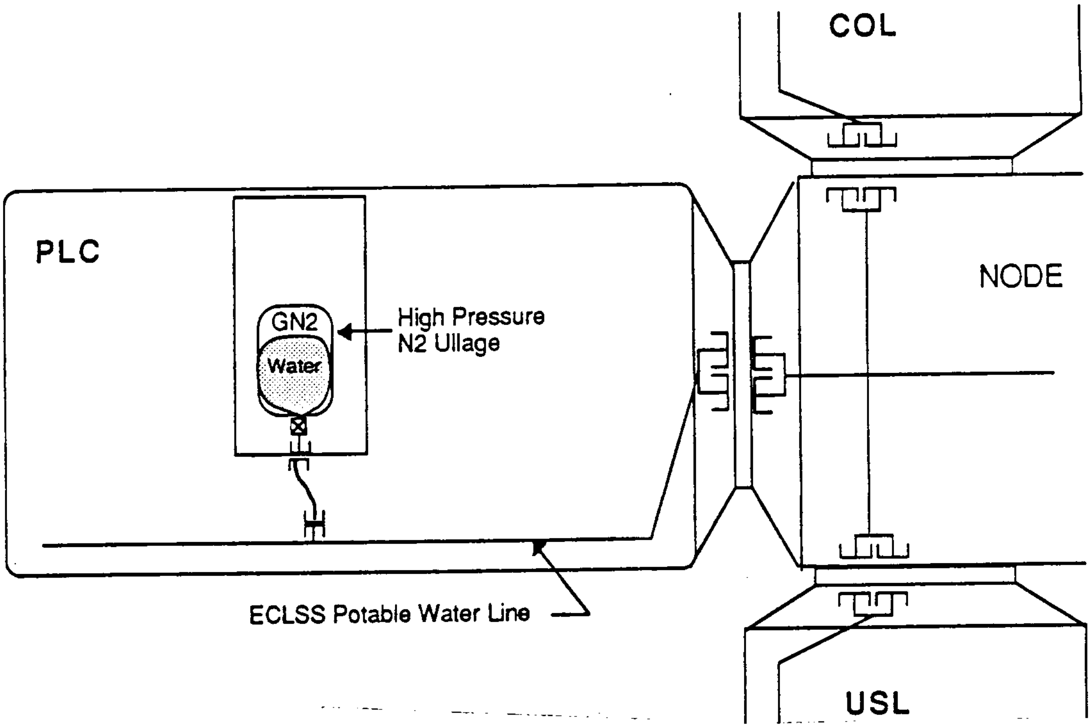

Figure 5.4-6 Option 6 - Water Resupply Tank with Blowdown from Pressurized Ullage

5.5 ON STATION WATER STORAGE AND DISTRIBUTION

The IWS Space Station distribution lines must conform to the requirements set out in the various NASA documents. These requirements include the following:

1) Water distribution plumbing consists of lines, valves, and QD's to facilitate the integration and distribution of all water to the various subsystem components and to and/or from the various water users (JSC 30262).
2) The collection, processing, and dispensing of water (with exception of laboratory waste water) to meet evolving Space Station crew and other potential needs shall be accomodated (SS-SRD-0001, Sec. 3).
3) The capability to disinfect/sanitize the water system shall be provided (Space Station Man-System Integration Standards, NASA-STD-3000).
4) Potable water shall be provided by closed loop, with capability of NSTS resupply (USL CEI (SS-SPEC-002)).
5) Processed water shall be supplied to accomodate PMMS resupply (USL CEI(SS-SPEC-002)).
6) Processed water shall be available for immediate use (USL CEI (SS-SPEC-002)) and (HAB CEI (SS-SPEC-0100)).
7) The system shall be designed to preclude inadvertent contamination of the processed water (USL CEI (SS-SPEC-002)) and (HAB CEI (SS-SPEC-0100)).
8) Water used to remove toxic or corrosive chemicals or other contaminants that would be hazardous to the crew shall be isolated from all other hygiene water sources unless it can be proven that the water recovery loop is able to remove the substance(s) from the water (HAB CEI (SS-SPEC-0100)).

Storage for these and other water requirements has been proposed to be in the form of potable water, with transfer taking place via the ECLSS potable water lines. The potable water lines run throughout each module and node, including the international modules. This scenario facilitates transfering water to the users without an additional requirement for dedicated lines. A connection is made to the ECLSS system racks in the HAB and USL modules to provide the input of ECLSS excess potable water generated into the node water storage. Thus non-experiment waste water is processed by the ECLSS system and put back into the system. Provisions are made for the transfer of make-up water from a PLC tank and of scavenged ultrapure water from the orbiter fuel-cells. There is a connection with the USL Process Material Management System (PMMS) to provide potable water to the experiments. The input is made to the pure side of the PMMS water recycle system to preclude connection to the potable water loop where there is contaminated water is on the other side of the connection. This eliminates both the need for a make-break connection and the requirement for crew intervention for fluid transfer from the potable water lines to the experiment strorage tank.

5.5.1 On-Board Water Storage Concepts

The Space Station water storage volume is divided between four identical water storage tanks. Each of the four tanks is located in one of the four nodes on the Space Station, as shown in Figure 5.5-1. The Gamma Ray Observatory propellant tanks are good candidates for use as water storage tanks. They will be space qualified by 1992, are diaphragm tanks for ease of fluid transfer, and are sized such that one tank will fit into a standard USL double rack. Distributing one tank into each node will increase safety, and placing them in standard racks will allow for modularity. Four tanks will provide a capacity of 5288 lbm, allowing a 10% margin for the worst case studied.

The water tanks are pressurized with N_2 supplied by the Integrated Nitrogen System (INS) as shown in Figure 5.5-2. Waste N_2 from the tanks is vented to the modules as leakage and air lock loss makeup. The vent rates are small (17 lbm/90 days) and the gas is pure and uncontaminated, thus venting directly from the diaphragm tank to the module will cause no safety problem. The station will leak about 4 lbm of N_2 per day and the ECLSS system is required to makeup this air loss. Using the water pressurization N_2 for cabin air makeup reduces resupply requirements by using the same gas twice.

Figure 5.5-3 shows the water stored in a pallet outside of the modules. This storage option may provide an advantage as volume is limited comodity on the Space Station, and four double racks would be freed for experiment use. Tank change out via a pallet in the ULC or PLC will be facilitated using the station or shuttle Remote Manipulator System. There are some problems with outside strorage, including: exposure of the water pallet to meteorite damage could cause catastrophic loss of reboost propellant; thermal conditioning of the water would be required; the cost of EVA repairs in the event of a water system failure is much greater than for IVA repairs; and the station pressure shell would have to be perforated for the water line to pass through.

5.5.2 On-Board Water Distribution

An important architectural decision to be made is that of a circulating versus non-circulating distribution system. A major concern is that microbial growth and biofilm formation may occur in locations where water does not flow. Data which conflicts with these concerns, such as that from shuttle experience, shows that high quality water with a residual halogen biocide does not require continuous circulation to prevent microbial growth.

The most promising approach for preventing growth without circulation is the one used on Shuttle, i.e. maintaining a residual biocide (iodine) concentration. Provision of circulation and biocide monitoring capability for the storage tanks may be necessary to ensure that proper biocide

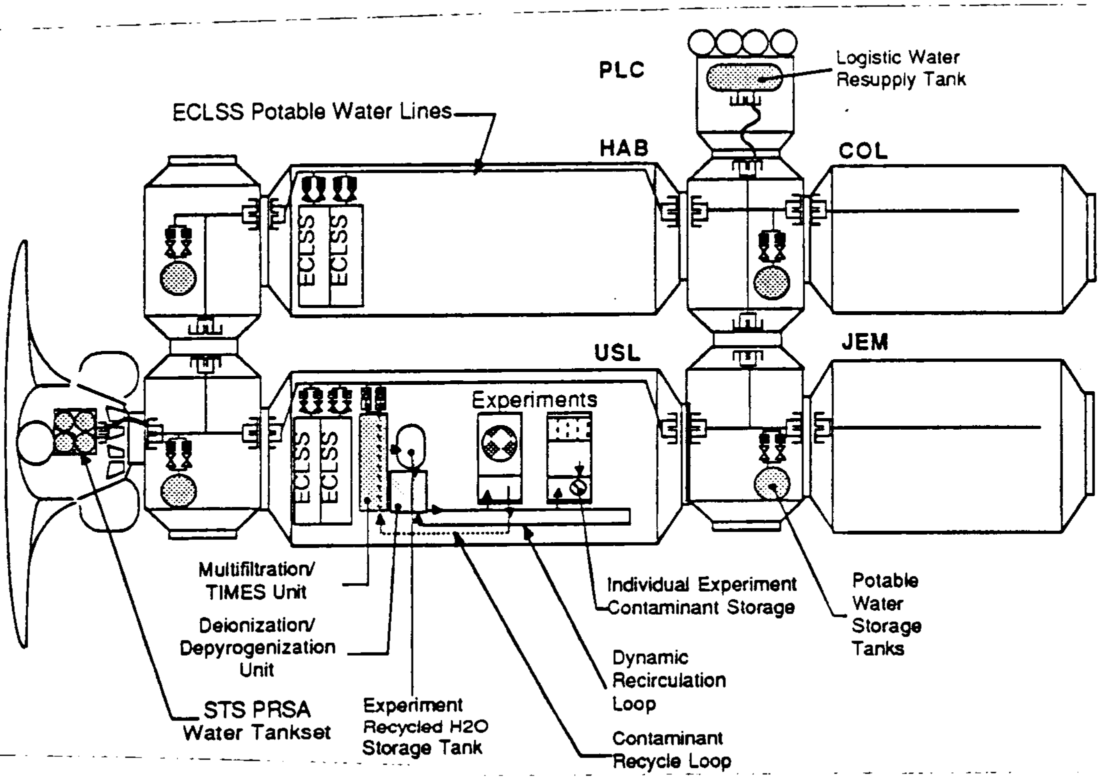

Figure 5.5-1 Potable Water Storage in Nodes

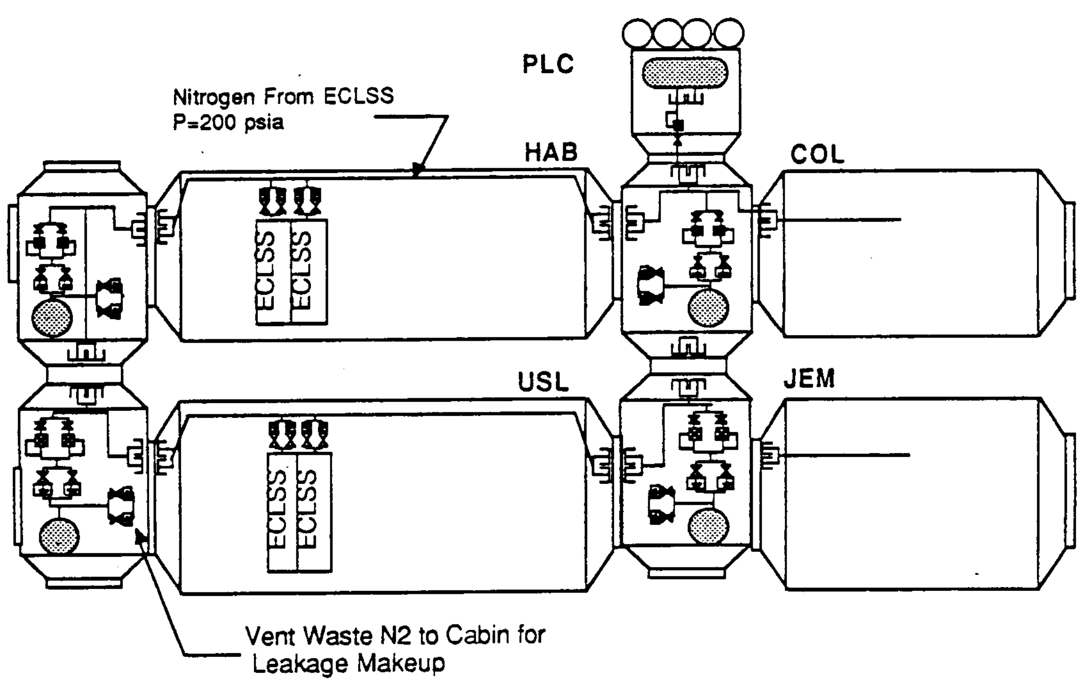

Figure 5.5-2 Integrated Nitrogen System Pressurization
of Potable Water Storage in Nodes

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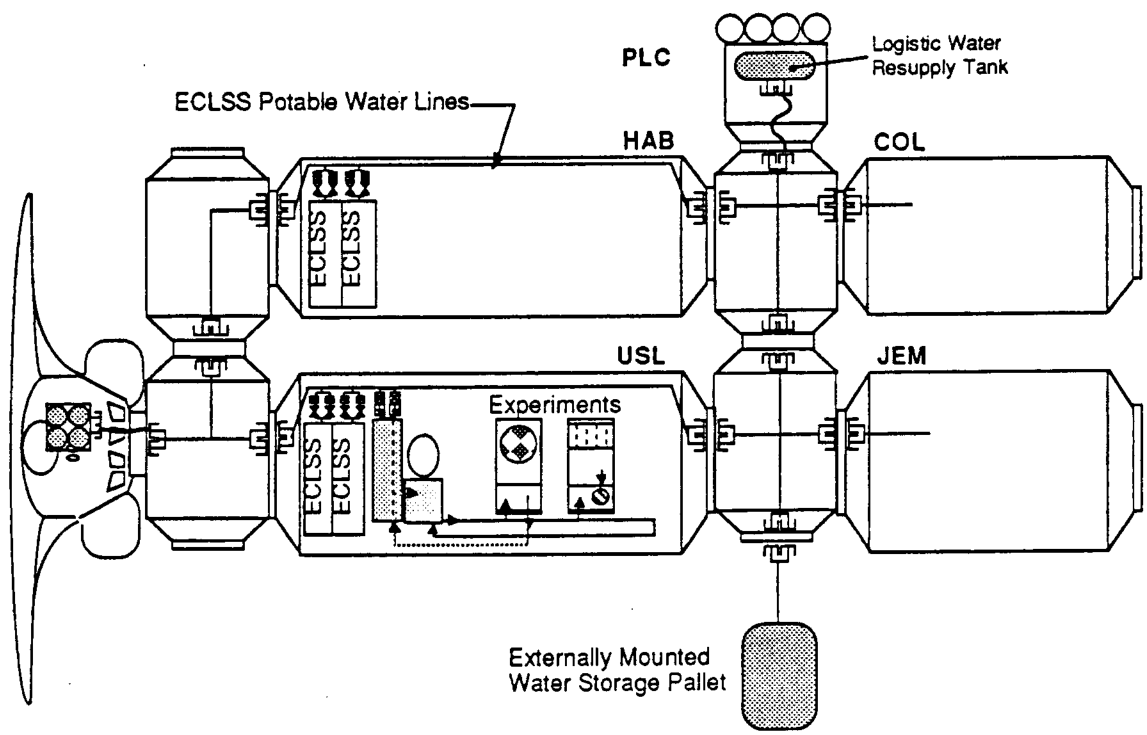

Figure 5.5-3 Water Storage Outside of the Modules

levels are constantly maintained. Microbial check valves (MCV's, iodinated resins) may also be required in-line in the water distribution piping to ensure maintanance of residual biocide, and to prevent migration of contamination. At a minimum, MCV's should be installed at all interfaces of the integrated water system to minimize the possibility of microbial back-contamination.

The final decision on circulating versus non-circulating distribution must be deferred until such time that sufficient long term tests with water, biocide, and piping materials can be completed.

Since the potential may exist for microbial contamination of the water distribution system, it is recommended that the system be designed to minimize the impact of inadvertent microbial contamination, and to provide the capability for microbial decontamination. Isolation valves should be included to provide the capability of isolating each module, as well as the piping runs in individual standoffs. Pressure and flow sensors provided in the piping for each standoff would aid in isolation of problems. Connections to individual racks should include an isolation feature. Connections should also be provided in each module endcone to accomodate orbital support equipment for decontamination. Several options have been identified for both chemical and microbial decontamination of water piping. These options are discussed Appendix B.

The baseline method of supplying experiment water to the JEM is to use Portable Pressure Vessles (PPV) launched into orbit in the Japanese Experimental Logistics Module (ELM). JEM and COL could be integrated into the IWS by supplying potable water for use in their experiments, and storing the waste water in Portable Waste Vessels (PWV). An ECLSS potable water line already runs into the JEM and COL. Therefore, disconnects and flex lines which tap off of the ECLSS line could be used to distribute the required amount of water. A dedicated waste water line from the JEM to the USL is too dangerous due to possible leaks and subsequent contamination of living spaces. One method of recovering the JEM or COL waste water is to hand carry the PWV's to the USL for proscessing by the WMS. The PWV would be a bladder tank and fluid transfer would be conducted by pressurizing the tank with the INS. The bladders could be changed out and disposed of in case of gross contamination, and the tank itself reused.

5.6 RECOMMENDATIONS

The decision on the final disign configuration cannot be made until further decisions are made regarding such things as the amount of water in the food, the frequency of orbiter visits, and the amount of circulation required. A concept has been presented which stores water in diapragm tanks in the nodes and uses a high food water conent (2.2- 2.68 lbm/man-day). This concept would provide the necessary water for any contingency situation.

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7) G. Colley, " Space Station Reboost Requirements For Assembly and IOC + 1 Year", Martin Marietta Memorandum, 30 January 1987.

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6.0 INTEGRATED NITROGEN SYSTEM

Nitrogen is an extremely important fluid requirement of the Space Station. The Integrated Nitrogen System (INS) is an integral part of the integration of the overall Space Station fluid management system. Requirements for the overall nitrogen system, fluid system interfaces, and fluid user interfaces have been established for the Initial Operating Capability (IOC) and for scarring for Post-IOC operations. Nitrogen is the primary constituent of air for life support, and is required for atmospheric control operations at IOC. Nitrogen is also required for potable water pressurization, experiments, and emergency life support operations such as safe-haven, hyperbaric airlock pressurization and module repressurization. Liquid nitrogen is required aboard the USL for cooling operations. Nitrogen will eventually be required for use by various vehicles, platforms and servicing facilities in support of the Space Station at Post-IOC.

The purpose of this assessment is to specifically address the commonality and integration issues of the integrated nitrogen system. Commonality and integration are very important factors in reducing the quantity of hardware used and its associated costs. Such a system will be capable of delivering nitrogen to any and all users on demand and at the required fluid conditions. The system will be developed so as to reduce hardware development, maintenance and resupply costs, enhance growth potential, and eliminate safety concerns.

A series of integrated nitrogen system candidates as they relate to commonality and integration issues have been developed and are presented in Section 6.5.6. System and fluid requirements were compiled and used for the development of subsystem concepts which were subsequently combined to form several overall integrated nitrogen system options. Systems capable of delivering gaseous nitrogen and comprising two levels of integration including variations of integrated configurations and one dedicated (partially integrated) fluid system configuration were developed. A method for resupply and delivery of liquid nitrogen for use in the USL is also discussed but not considered to be integrated with the gas delivery systems. The proposed system candidates are documented through a host of system schematics, components/parts lists with component weight and pressure requirements. The system interface requirements are presented in detail in EP 2.2, Space Station Program Fluid Inventory Databook. Comparisons of the options were performed using trade studies, thermodynamic analyses and the Integrated Cost Model developed under Task I of this contract. The cost model was used to perform a cost comparison of the systems. Results of the cost model assessment are presented in Section 6.5.8. Conclusions and recommendations are made concerning the nitrogen system candidates evaluated with regards to costs and integration criteria while discussing the advantages and disadvantages of each.

6.1 INTEGRATED NITROGEN SYSTEM OVERALL REQUIREMENTS

The INS will supply gaseous nitrogen to the Environmental Control and Life Support System (ECLSS), Integrated Water System (IWS), U.S. Laboratory (USL), Columbus (COL) and the Japanese Experimental Module (JEM) interfaces at the required pressures by regulating down from higher pressure delivery. The system will interface with the USL and Habitation modules via interfaces at the modules and Nodes 1 and 2. The JEM and Columbus modules interface the INS distribution lines at Nodes 3 and 4 which are located between the US and international modules. Waste nitrogen is directed from the experimental modules to the Integrated Waste System (IWS). Furthermore, the INS is scarred for Post-IOC operations and for future growth. This requirement is met with disconnects on the station truss structure which will remain idle until Post-IOC. Post-IOC requirements include high-pressure nitrogen support for Extravehicular Activity (EVA) Systems such as the Manned Maneuvering Unit (MMU), Extravehicular Excursion Unit (EEU), the Enhanced Mobility Unit (EMU), the Orbital Maneuvering Vehicle (OMV) and the Servicing Facility. The Servicing Facility is also required to have a supply of low-pressure nitrogen. The Post-IOC scarring requirements are described in Section 6.5.9.

6.2 INTEGRATED NITROGEN SYSTEM REQUIREMENTS

In addition to the overall INS system requirements, the INS must comply to requirements for growth, design, fluid storage, hardware selection and system monitoring[1]. The system shall possess the capability for growth and reconfiguration to satisfy fluctuating and changing user demands. The system shall be designed and integrated so as to minimize hardware requirements, hardware development, and resupply quantities by recycling pure gaseous nitrogen waste effluents and redirecting them wherever and whenever possible. In terms of hardware commonality (hardware design and implementation), an integrated system will use fewer types of components and fewer copies of each component type in the subsystem designs. Standardization of fluid system components is required for ease of maintenance and to preclude the mating of incompatible components. Pressures, temperatures, flowrates and storage quantities shall be monitored to insure proper fluid conditioning over a resupply cycle. Overall, these requirements will reduce development and operational costs, and insure that the integrated system will provide full operational capability while mitigating operational delays.

6.3 INTEGRATED NITROGEN SYSTEM DEFINITION

The INS system consists of a supply subsystem, a storage subsystem and a distribution subsystem. The resupply fluids pallet comprises the supply subsystem which provides the primary storage and supply location for satisfying normal user requirements. One fluids pallet configuration will be used to transport nitrogen into the station for resupply of the ECLS system by means of the integrated nitrogen distribution subsystem. The emergency storage subsystem will provide nitrogen for emergency or contingency purposes such as safe-haven operations, for pressurization of the hyperbaric airlock chamber, for module repressurization, and for a skipped cycle. The contingency requirements are consistent with a skipped cycle, accomodating normal user requirements for 45 days[2]. The emergency storage subsystem may also be used to supply nitrogen for specific user demands in the event that the primary supply subsystem becomes incapacitated. The distribution subsystem is comprised of external high pressure and internal low pressure gaseous nitrogen delivery lines. This system transfers high pressure nitrogen gas in the external system and regulates it to a reduced pressure of 200-750 psia[1] for low-pressure use. Nitrogen at low pressure is delivered at a nominal temperature of $70^{o}F$[1], and is required at all of the normal user interfaces at IOC. High-pressure gas delivery is required for resupply of storage subsystem tanks during blowdown transfer, or for Post-IOC operations where scarring is required.

The integrated nitrogen system performs numerous functions in the process of managing all of the gaseous nitrogen required by users. It performs the functions of resupply, transfer, storage, fluid conditioning, and the control and monitoring of supply and delivery conditions. The supply subsystem must be resupplied every resupply period, or every 90 days[1], in order to assure that the appropriate amount of nitrogen will be stored and available for normal use. Fluid storage and delivery conditions must be continually monitored so that nitrogen is maintained and delivered at the proper temperatures and pressures and storage levels are known for scheduling and resupply purposes. Hardware commonality is designed into the overall INS by developing the subsystems with the same hardware types where possible.

6.3.1 Supply Subsystem Definition

The INS supply subsystem consists of the tankage, structural, mounting, conditioning, thermal control, transfer, and control and monitoring hardware necessary for delivery of the nitrogen to the distribution subsystem and then to the user interfaces. The supply subsystem hardware will be delivered by the Logistics Elements as a fluids pallet encompassing the above hardware. Operational flexibility in the supply subsystem is enhanced by incorporating conditioning hardware specific to a given resupply concept within the subsystem pallet, such as heaters, pumps, compressors, or any other components necessary to condition the nitrogen in the pressure vessels. By including items requiring periodic maintenance on the supply pallets, on-orbit maintenance can be eliminated. The INS supply subsystem pallet is primarily responsible for performing the dual function of resupply and storage of nitrogen for normal every day operations. It also performs a secondary function of resupplying nitrogen for transfer to the storage subsystem. The supply subsystem pallet configuration allows for the incorporation of additional pressure vessels when the normal user nitrogen requirements change or grow over the life of the Space Station[3,4].

Two redundant interface locations are allocated for supply subsystem pallets. These interfaces are optimally located to simplify on-orbit resupply, EVA maintenance and nitrogen delivery operations. A single fluids pallet resupplied every 90 days will occupy one of the interface locations. The second interface location is available for docking of a resupply pallet for a subsequent resupply period, allowing resupply pallets to overlap while nitrogen from the existing fluids pallet is still being consumed during a subsequent resupply period. An overlap period may extend up to many days while the NSTS shuttle remains docked to the station. Under these conditions, the first pallet would not be deorbited until the next resupply period. In addition to allowing for resupply overlap, the second interface location may allow for docking of a resupply pallet used strictly to transfer nitrogen to the storage subsystem (see Sections 6.3.2 and 6.5.7).

6.3.2 Storage Subsystem Definition

The INS storage subsystem will provide sufficient storage to satisfy emergency ECLSS and contingency requirements[5] for gaseous nitrogen. The storage subsystem is comprised of a permanent, on-board gaseous nitrogen storage pallet system similar in nature to that of a supply subsystem pallet, except that it is permanently affixed to the SS truss structure. The storage subsystem pressure vessels are resupplied from the supply subsystem either with the use of compressors or through a blowdown transfer process. A high pressure gaseous storage subsystem concept was selected on the basis of its simplicity in design and its capability for long-term storage since it is required for emergency use only. The option for a cryogenic storage subsystem is eliminated since such a system will require excessive monitoring and conditioning. The gaseous system has a high potential for blowdown resupply without the use of additional transfer or conditioning hardware. The storage subsystem is located external to the pressurized modules, like the supply subsystem, and is required to have two independent isolated pressurized volumes[5], each with the capability to supply the full amount of emergency and contingency nitrogen. This is required so that in the event that one pressurized volume is lost, another will be available immediately.

The storage subsystem nitrogen requirements, as mentioned before, are established for emergency situations such as repressurization of a module, hyperbaric airlock pressurization and contingency use when a resupply cycle is skipped. Similar to the supply subsystem flexibility, the storage subsystem pallet configuration will allow for the incorporation of additional pressure vessels should the emergency nitrogen requirements ever change or grow, or the operational requirements of the storage subsystem ever deviate.

6.3.3 Distribution Subsystem Definition

The INS distribution subsystem will deliver nitrogen from the INS supply subsystem interface to user interfaces at required temperatures and pressures. It delivers nitrogen that is blown down or compressed at a higher pressure and then regulated down to the final delivery pressure. In-line nitrogen delivery or transfer compressors, if required, will become an integral part of the INS distribution subsystem. Certain INS configuration candidates require compressors for delivery and/or transfer. This will be seen later in Section 6.5.6.

The INS distribution subsystem will consist of the plumbing, connectors, mounting, conditioning, thermal control, transfer, and control and monitoring hardware necessary for nitrogen distribution to the user interfaces. This system is comprised of the valves, filters, disconnects, check valves, regulators, etc. to direct and control the distribution of nitrogen to the desired interfaces. This hardware includes any compressors necessary for nitrogen delivery to users or for repressurization of the storage subsystem. The plumbing consists of both high and low pressure lines. The high pressure gaseous lines are mounted external to the pressurized portion of the station and located along the truss structure. These lines are integrated with the supply and storage subsystems at their interfaces and at the user interfaces. Low pressure distribution lines run internal to the pressurized portions of the SS and interface the ECLSS distribution subsystem. The ECLSS distribution subsystem routes nitrogen through the nodes surrounding the USL and HAB modules (Nodes 1 and 2) and through the modules themselves from the ECLSS racks. The ECLSS racks are located in both the USL and HAB modules comprising redundant systems. The ECLSS distribution subsystem is interfaced by the INS distribution subsystem at Nodes 3 and 4 (between the US and international modules) by the fully integrated systems to further distribute nitrogen to the international modules and to the USL experiments. The INS distribution subsystem is also scarred on the truss structure for eventual high and low pressure use by Post-IOC EVA systems and for future growth.

6.4 INTEGRATED NITROGEN SYSTEM USER FLUID REQUIREMENTS

The nitrogen user fluid requirements were established by compiling the best data possible from Space Station documents, contractor data, and Martin Marietta databooks regarding the required nitrogen user interfaces. Table 6.4-1 lists the nitrogen quantities that must be supplied, or available in the case of the storage subsystem, over any 90 day resupply period. Note that the last three figures represent the fluid quantities that must be available on board for potential emergency and contingency use and not quantities that are readily used over each resupply period. Similarly, Table 6.4-2 lists the fluid storage requirements per 90 day resupply period for the supply and storage subsystems.

6.5 INTEGRATED NITROGEN SYSTEM ASSESSMENT AND ANALYSIS

6.5.1 Integrated Nitrogen System Resupply/Storage Techniques

Essentially, three methods or techniques by which nitrogen will be resupplied and stored were defined. Resupply/storage concepts which allow the nitrogen resupply to be brought up as a high pressure gas (supercritical fluid) and as a cryogenic supercritical fluid have been defined on the subsystem level (supply subsystem) and were incorporated into overall integrated system configurations. In addition, a subcritical liquid resupply/storage concept for the supply subsystem was looked at as a third concept for the Integrated Fluid System Assessment and Analysis Tasks and likewise integrated into the storage and distribution subsystems. The comparison of high pressure gas and cryogenic supercritical resupply/storage techniques will be the primary focus of attention in this assessment. No mention has been made for a dedicated nitrogen supply or distribution system, however one configuration of note for gaseous users has been developed and an assessment was made. A dedicated LN_2 system is discussed in Section 6.5.6.3. The following is a list of the nitrogen resupply/storage concepts (supply subsystems) considered with a brief description of each :

6.5.1.1 High Pressure Gaseous (supercritical) Nitrogen --- SSIPFSS Reference Concept - The high pressure gaseous resupply/storage concept, or supercritical nitrogen resupply/storage concept as it is also called, is the simplest, most widely used method with which to store nitrogen for use as a gas. This concept was selected as the SSIPFSS Reference Concept for a multitude of reasons. Overall, since this type of system is less complex in terms of hardware, thermal conditioning required, and the method by which nitrogen is supplied to the distribution system, it

Table 6.4-1 Integrated Nitrogen System User Fluid Requirements (IOC)

FLUID REQUIRED SYSTEM INTERFACE	QUANTITY (LBM/90 DAYS)*	REMARKS
ECLSS	412[6]	- Continuous supply to ECLSS Distribution Subsystem
IWS	27[3]	- Potable water tank pressurization
IWFS	TBD	- Waste water pressurization
USL Module	99.1[3]	- Experimental use
JEM Module	13.5[7]	- Experimental use
Columbus Module	13.5***	- Experimental use
Airlock Repressurization	67[6]	- Airlock loss makeup (EVA days)
Hyperbaric Airlock Pressurization	274****[8]	- Emergency airlock press. (6 atm)
Module Repressurization	353****[8]	- Repress. of repaired module
Skip Cycle (Contingency)**	269	- 45 day normal user requirements
USL Module (cooling LN2)	608[3]	- cooling purposes for experiments in USL

* 90 day resupply requirements
** Requirements for normal operations if resupply missed (limited experiment nitrogen)
*** Groundruled equivalent to JEM (SSIPFSS Program)
**** Based on best available estimate from Martin Marietta Space Station team (these figures are similar to values in the reference document)

Table 6.4-2 Integrated Nitrogen System Fluid Storage Requirements (IOC)

SUBSYSTEM	REQUIRED FLUID QUANTITY (LBM/90 DAYS)	REMARKS
Supply Subsystem	632 ±	- Supplies normal GN_2 user requirements - Two pallet interface locations - Second pallet interface for layover or for storage subsystem transfer - Only one primary supply pallet utilized to supply normal user requirements
	608±	- LN2 supplied as independent dewar for cooling in USL only

Contingency Storage Subsystem	896 ±	- Two redundant pallets isolated from one another - high pressure gas delivery
		- Requirements for emergency use only
		  - HAL pressurization
		  - module repressurization
		  - skipped cycle (contingencies)
		  - cabin atmospheric control
		  - experimental use
		- Resupplied by Supply Subsystem
		  - blowdown transfer
		  - compressed transfer

± variation in the exact resupply quantity is an attractive option. Furthermore, costs for hardware development and production will be lower as will be the costs associated with maintaining a less complex storage system. In contrast, the resulting high pressure vessels are larger and heavier in mass than their cryogenic tank counterparts because they are maintained at higher pressures, thus requiring larger and thicker pressure vessel designs. Higher operating costs may outweigh savings due to the design's simplicity. Figure 6.5-1 illustrates this concept in relation to all of the necessary hardware requirements.

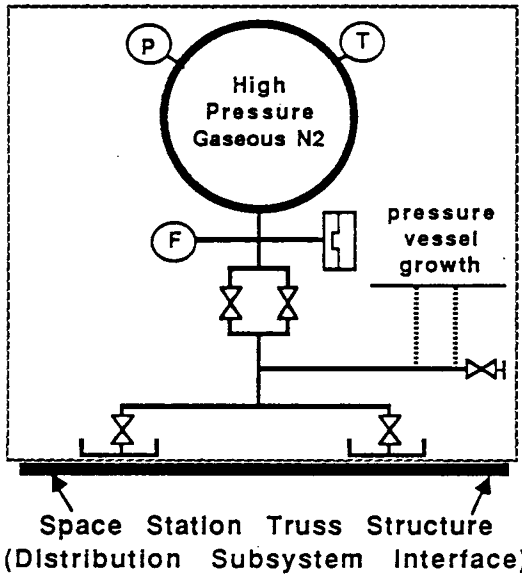

Figure 6.5-1 High Pressure Gaseous Nitrogen Resupply/Storage Concept

6.5.1.2 <u>Cryogenic Supercritical Nitrogen --- Alternate Concept 1</u> - Another method of resupply and storage, termed the cryogenic supercritical approach, possesses unique characteristics of its own. Nitrogen is initially brought up as a cryogenic supercritical fluid, possessing properties of a cryogenic fluid, yet maintained at a constant high pressure above the critical pressure of nitrogen (493 psia). Below the critical pressure, the nitrogen would condense to a liquid, creating fluid management problems. By maintaining the nitrogen at cryogenic temperatures and at a constant pressure above the critical pressure, the fluid possesses some of the properties of liquid, but is uniform in its mixture and fills the tank volume as would a gas. Since it is neither a liquid or a gas in nature, it is termed a dense fluid. The high pressure allows for a blowdown supply, precluding the need for liquid pumps. As the fluid is depleted, the specific volume of the fluid increases, which in turn increases the amount of conditioning required to sustain the supercritical pressure. Tank conditioning is accomplished when some of the fluid from the pressure vessel is heated and recirculated (with heaters and recirculation pumps) back into the tank to maintain the pressure at an operating level above the critical pressure. Through the process of continually heating the tank to maintain pressure, the tank temperature may increase to unnecessarily high levels at the expense of a great deal of heater power. The system developed here only allows the temperature to extend to nominal delivery conditions of 70°F from which it is blown down as a high pressure gas at constant temperature. Such a system could expel nitrogen as a gas when the tank temperature exceeds the critical temperature of nitrogen (227°R). In this manner, the need for large amounts of power to maintain critical tank conditions could be eliminated and only a minimal amount of power would be required for heating the fluid to maintain user temperatures.

The cryogenic supercritical resupply/storage technique has advantages and disadvantages inherent in its design and implementation. The primary advantage is that this method allows the resupply of a larger mass fraction of nitrogen while allowing for supply blowdown. On the other hand, cryogenic supercritical pressure vessel designs are still in development stages even though they have been applied to and qualified for specific uses; i.e. the shuttle PRSA tanks. This type of system will require further technology development and test qualification for its specific application on the space station. Another factor that disputes the practicality of such a system is the quantity of hardware necessary to condition the fluid in the tank and for nitrogen delivery to the user interfaces. This includes heaters both for tank heating and for user fluid heating. The delivery heater is really only necessary in the early stages of storage when the fluid is cryogenic. A fluid recirculator pump and internal tank mixer is also required to establish a homogeneous fluid mixture within the vessel. This system is much lighter in weight than the high pressure gas concept even when considering the number of different types of components it is comprised of. Figure 6.5-2 illustrates this concept in detail. Shown is only a single pressure vessel although the capability exists with which to add additional vessels to the pallet as growth concerns dictate. As additional cryo-supercritical pressure vessels are added to the pallet system, the conditioning hardware required by each is added, or at least a redundant set of conditioning hardware for overlapped use of more than one supply vessel when the transition is being made from one tank to another.

6.5.1.3 Subcritical Liquid Nitrogen --- Alternate Concept 2 - The last of three options proposed as candidate nitrogen resupply/storage system concepts is the subcritical liquid or liquid nitrogen technique. In this concept, nitrogen is brought up as a saturated cryogenic liquid, trapped by a liquid acquisition device and pumped out of the tank to the appropriate pressure and heated to the desired temperature for use. A pump and a heater are needed for the delivery conditioning process. A tank pressurization loop is incorporated into the concept design, functioning to provide a net positive pressure head on the fluid system for acquisition and pumping. This may be either an autogenous system where a small portion of the fluid expelled from the tank is heated and rerouted back into the tank, similar to the process used for tank conditioning of the cryogenic-supercritical system, or a system utilizing a pressurized helium source for liquid pressurization. Figure 6.5-3 illustrates this supply subsystem concept with the autogenous pressurization system. The system using helium for tank pressurization is shown in Figure 6.5-4. Note that the system with helium pressurization is the most hardware intensive of the supply subsystem options, similar to the cryogenic-supercritical concept. It is important to mention that a high degree of expulsion efficiency is attained from this system in addition to the advantage of bringing up the lightest supply subsystem with the largest fluid resupply mass fraction.

The subcritical liquid system is severely limited in its performance due to many different factors. First and foremost, cryogenic liquid tanks of this nature have not been able to effectively vent themselves in a low-g environment, posing operational limitations on the system. A possible solution to the venting problem might be to incorporate a thermodynamic vent system (TVS) with a tank heat exchanger of sorts, but this adds to the hardware and fluid requirements, and to the implications of venting or recycling cooling fluid. The autogenous pressurization system will inevitably result in tank heating over time, especially over the long time period between resupply missions, consequently requiring higher tank pressures for liquid acquisition and pumping. Although the helium pressurization system will alleviate high pressure and high temperature conditions in the tank, it may contaminate the stored nitrogen and adds to the hardware complexity of the resupply pallet and the supply subsystem.

6.5.2 INS Reference Configuration

The Integrated Nitrogen System Reference Configuration is comprised of the high pressure gaseous resupply/storage concept as the supply subsystem as described in Sections 6.3.1 and 6.5.1.1, and the integrated storage and integrated high pressure gaseous distribution subsystems

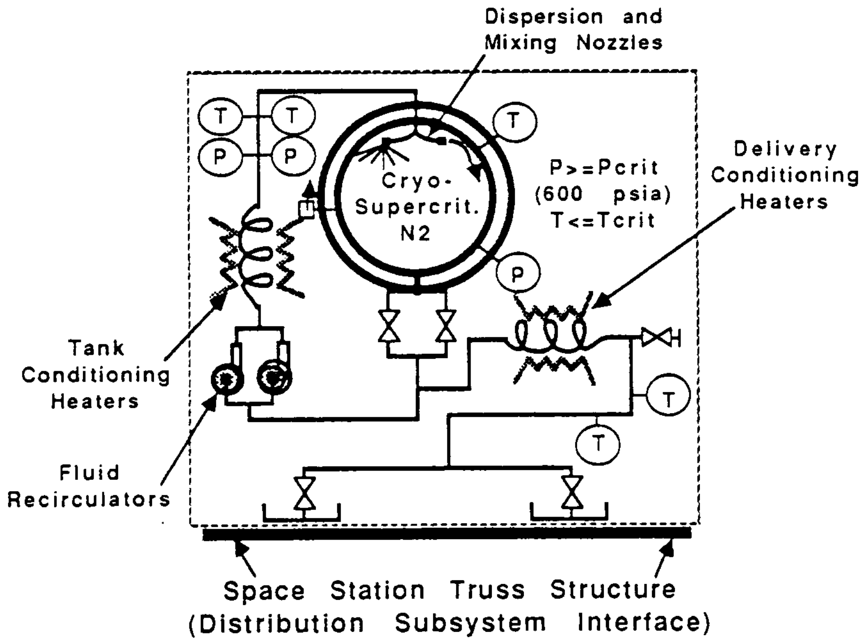

Figure 6.5-2 Cryogenic Supercritical Nitrogen Resupply/Storage Concept

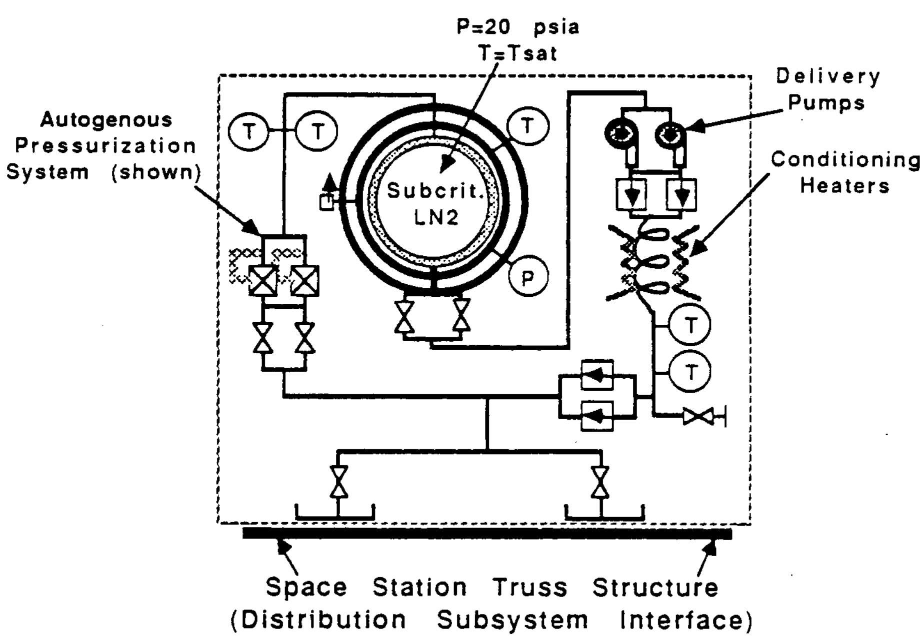

Figure 6.5-3 Subcritical Liquid Nitrogen Resupply/Storage Concept (Autogenous Pressurization)

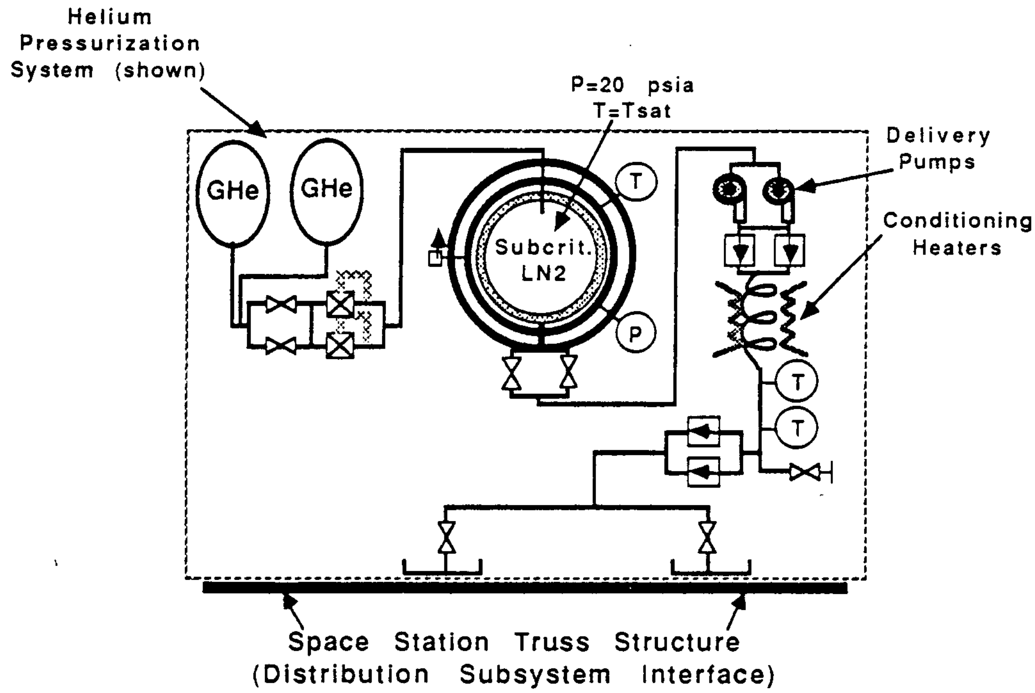

Figure 6.5-4 Subcritical Liquid Nitrogen Resupply/Storage Concept (Helium Pressurization)

described in Sections 6.3.2 and 6.3.3.

The reference INS configuration is illustrated in Figure D-2 and described below. The supply and storage subsystems are composed of all of the neccessary hardware for conditioning and delivery of gaseous nitrogen with the exception of the compressors needed for delivery to users or for fluid transfer to the storage subsystem. This includes the pressure vessels, pressure relief valves, redundant latch valves, any fill and drain valves, and quick disconnects for mating the pallet interface to the distribution system. The supply subsystem pressure vessels are supplied to 3,500 psia and will blow down to 250 psia, at which point delivery compressors take the tank pressure down to 20 psia and compress the nitrogen to maintain the 250 psia delivery pressure (see nitrogen Configuration #1, Option 1B in Section 6.5.6.2.A.). The reference storage subsystem contains one gaseous nitrogen pressure vessel which is kept full at a pressure of 1,000 psia. This was chosen as the reference storage subsystem because it allows simplification of the blowdown transfer process and was the lowest pressure option studied. A trade study was performed whereby different high pressure gas storage subsystem configurations were evaluated based on operating pressure, number of pressure vessels, size of vessels, nitrogen fill quantities and how they pertain to the logistics of resupply and fluid transfer from the supply subsystem. The results of this study will be presented in Section 6.5.7, INS Contingency Storage Subsystem Tank Study.

The distribution subsystem interfaces with the supply and storage subsystem pallets through doubly-redundant disconnects at pallet interfaces. The system extends, both externally and internally to the user interfaces of the pressurized modules. Compressors are incorporated inline with the distribution subsystem high pressure lines running along the truss structure (see Figure

D-2). The distribution lines within the Space Station modules are considered an integral part of the overall distribution system, but do not include the ECLSS distribution subsytem lines which serve as the interface between the ECLSS and the INS disribution subsystem interface. The distribution subsystem high pressure lines penetrate Nodes 1 and 2, after which the high pressure gas is regulated down to pressures between 200 and 750 psia[1]. The distribution subsystem is required to penetrate the pressurized elements at two different locations so that the interface to the ECLSS is two failure tolerant (crew safety critical)[2]. Loss of any one pressurized element or failure of any branch of distribution still leaves at least two paths of distribution (triply redundant) to the ECLSS distribution subsystem loop. The distribution subsystem lines continue from the ECLSS interface and penetrate Nodes 3 and 4 at the international modules for delivery to experiments in the JEM and Columbus modules. Since it runs through the HAB and USL modules, the ECLSS distribution subsystem loop is integrated with the INS distribution subsystem for delivery of nitrogen to the USL experiments.

6.5.3 Integrated vs. Dedicated System Approaches

Definitions of *integrated* and *dedicated* systems for this study are based on the interfaces they serve. A system is considered integrated if it satisfies the nitrogen requirements of more than one of the nitrogen users. A system is defined as dedicated if it supplies and delivers nitrogen or other fluid to one or more systems or users, but not to all users or systems that require nitrogen. In this sense, a dedicated system may also be integrated, but it will be integrated to varying degrees or levels of integration since it does not support all of the gaseous nitrogen users on the station. As an example, if the dedicated system provides nitrogen only for experimental users, then it will be integrated to a *system level of integration.*

The highest level of integration, termed a *fully integrated* nitrogen system, will entail the integration of a single supply and delivery configuration with all of the user interfaces/systems that require gaseous nitrogen at IOC. The fully integrated system for gaseous nitrogen will be integrated to a *space station level of integration* . The INS Reference Configuration is such a system.

A nitrogen system dedicated to some but not all nitrogen users is considered fully integrated within itself; however, in the arena of total gaseous nitrogen users, the overall nitrogen system will be *partially integrated.* This is not to say that a system dedicated for providing liquid nitrogen required for cooling in the USL constitutes a partially integrated system, because the liquid nitrogen system is treated independently of the gaseous system. The integration of liquid and gaseous nitrogen systems into one system is difficult and highly impractical for each of the concepts, except possibly the subcritical liquid resupply concept.

For all practical purposes in this study, the liquid system is treated independently and the levels of integration will be referred to the gaseous nitrogen systems and users. The possibilities of integrating the liquid nitrogen system into the integrated gaseous systems and of implementing it independently will be discussed in Section 6.5.6.3, Liquid Nitrogen Configuration Options. Where it is discussed that the overall gaseous and liquid systems are integrated together will be referred to as a *totally integrated* system.

A *fully dedicated* nitrogen system is one in which independent nitrogen supply and delivery systems support single users, dedicating supply and distribution systems to each user. Figure 6.5-5 shows how the various levels of integration compare for the gaseous systems.

6.5.4 Integration Criteria

In order to develop and screen potential nitrogen system candidates, a set of *integration criteria* have been developed. These criteria were established to determine whether a potential candidate

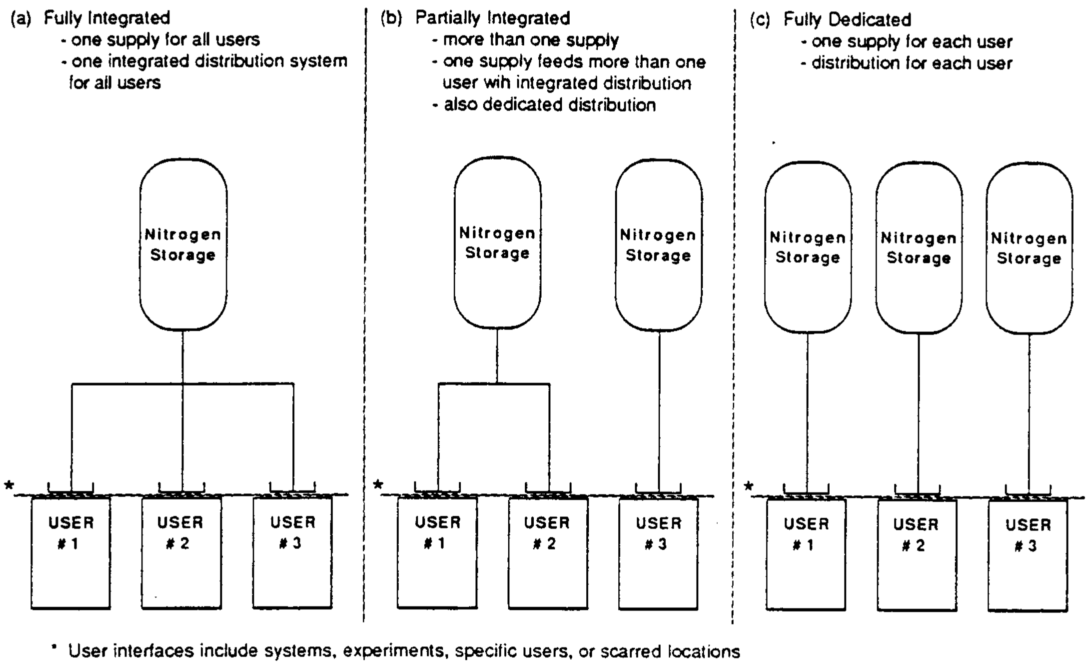

Figure 6.5-5 Levels of Integration of Gaseous Nitrogen Systems

system will benefit from integration or not, and were used as a basis for comparing advantages and disadvantages of the candidate GN_2 systems. The criteria will be used to develop a candidate configuration that is partially integrated (dedicated) and candidates that are fully integrated. Following is a list of the criteria established with discussions that might affect whether a system should be integrated or not :

6.5.4.1 Growth - Over the course of operation of the space station, fluid demands for nitrogen are going to grow. In particular, the nitrogen used for experiments in the USL is expected to grow by a factor of 10 from IOC to the full operating capability (FOC)[3]. Therefore, a nitrogen system must be able to accomodate this growth in the demand for nitrogen and be able to grow itself.

6.5.4.2 Logistics - There are considerations to make regarding the logistics of resupply in order to insure that the proper quantity of nitrogen is brought up for resupply. It is desirable to bring up only the amount of nitrogen that is actually going to be used with minimum residual, if possible, so that there is not a deficient supply for users or a need to deorbit unused nitrogen when the tanks are returned to earth. Fluctuating and growing experiment nitrogen requirements from IOC to FOC, especially in the USL for experiments, could confuse the fluid requirements planning for nitrogen resupply.

6.5.4.3 Operational Flexibility - Through the course of the Space Station life, the nitrogen requirements will undergo great changes. These changes will include quantities and number of users, and may include supply pressures and flowrates. The changes that must be made to a system's configuration in order for it to meet the changing requirements constitute its operational flexibility. Systems which require very little change in configuration for changes in the nitrogen requirement possess a great deal of operational flexibility.

6.5.4.4 Maintenance - Maintenance is the amount of repair work that must be performed to keep a system operating properly. This includes repairs, replacements, and periodic cleaning, adjustments, etc. Maintenance is measured in terms of both hardware and crew time, and crew time is broken down into three types, EVA, IVA and ground maintenance operations. All in all, maintenance is translated into costs. The maintenance required will increase as the number and complexity of components increases for any given system.

6.5.4.5 Commonality - Fluid system hardware commonality is achieved when the same components or types of components are used from one fluid system to another. The degree of commonality affects the design and the inherent cost of a fluid system. Systems with high degrees of commonality share the same components or component types and reduce the number of components required. The lowest cost system may constitute the optimum design of that system, but the common optimum design of the system will share a high degree of commonality with the common optimum designs of other fluid systems. In other words, the common optimum designs will use the same types of components as other fluid systems, thus reducing the overall cost of the overall Space Station fluid management system.

6.5.4.6 Cost - The cost is defined as the Life Cycle Cost (LCC) of the system. Life Cycle Cost includes the component design, development and test costs, manufacturing (production), procurement, spare parts costs, launch and deorbit costs, and the costs associated with EVA and IVA maintenance support. Technology factors will impact a system's cost by weighting the recurring and non-recurring costs. The LCC of a system greatly reflects the level of commonality and integration of that system. Systems that are cost effective reduce the hardware requirements in terms of the numbers and types of components due to their high degree of commonality. Cost tends to parallel a system's level of commonality.

6.5.4.7 Technology Risk - Technology risk is the uncertainty that the necessary technology for components or systems can be developed in a timely fashion with design and implementation. With regards to the integrated nitrogen system, there exists high uncertainty that the technology to successfully implement the subcritical liquid resupply/storage concept will exist.

6.5.4.8 Contamination - The venting or dumping of residual or waste nitrogen may not fall within the limits of the requirements defined by the Space Station Program.

6.5.5 Hardware Component Redundancies[2]

Redundancy requirements have been imposed on the development of systems comprised of multiple hardware assemblies in order to establish a fail-safe system. This redundancy of components allows a spare built into the system to be immediately available if a component happens to fail. The following redundancy requirements have been imposed on hardware elements used in the integrated nitrogen system :

Zero failure tolerant --- Single redundant (non critical)
- delivery lines

One failure tolerant --- Double redundant (mission critical)
- valves, filters, regulators, quick-disconnects

Two failure tolerant --- Triple redundant (crew safety critical)
- ECLSS system interfaces

In general, double-redundancy is implemented into the design when mission-critical hardware components such as valves, filters, regulators or disconnects are required for single failure tolerance, and triple-redundancy, or a two failure tolerant system is incorporated where a situation is life-critical. The interface to the ECLSS is considered crucial to life, whereas the remaining system interfaces are only mission-critical. The nitrogen distribution lines have no failure tolerance since they are expected not to fail.

6.5.6 INS Potential Candidate Configurations and Options

A series of potential INS candidate configurations with options have been developed. These sytems are presented in detail in this section. All of the candidates developed represent fully or partially integrated gaseous nitrogen systems. A fully dedicated system is impractical from a hardware standpoint and unnecessary since the majority of users have the same nitrogen delivery requirements. A fully dedicated system would constitute unnecessary individual system optimum designs. Integration of the gaseous nitrogen system is the optimum approach due to the large number of users and their close proximity with each other. Only one of the configurations is a partially integrated system and it is comprised of a dedicated fluids rack for experiments (Configuration 4, similar to the representation in Figure 6.5-5(b). A fluids pallet is configured for supply to the ECLSS and remaining users.

Again, the liquid system for the USL is considered independent until further requirements definition is obtained on the overall uses of liquid nitrogen by the Space Station. A discussion of this system is detailed in Section 6.5.6.3.

There are a total of four candidate gaseous configurations comprised of many options. Configuration 1 is the fully integrated INS that uses a high pressure gas (supercritical) resupply/storage concept for the supply subsystem. A total of four options of this configuration have been developed. Configuration 2 is the fully integrated INS that uses a cryogenic-supercritical nitrogen resupply/storage concept (Alternate Resupply/Storage Concept 1, Section 6.5.1.2, Figure 6.5-2) for the supply subsystem. Six options of this configuration were developed for evaluation. The last of the fully integrated gaseous configurations resupplies nitrogen as a subcritical liquid for the supply subsystem (Configuration 3, Figures 6.5-3 and 6.5-4). The subcritical liquid concept was evaluated because it was felt that its credibility should be investigated. Only a single option of this configuration was developed for evaluation. It is thought that this configuration will probably not possess any merit since such a system is still in the stages of development and qualification and has inherent high technological risk associated with it. The system LCC costs were determined and a comparison based on the integration criteria was made and reported here. The last configuration, Configuration 4, is the partially integrated system which is comprised of a dedicated fluids rack for the experiments and a fluids pallet for the ECLSS system and other users. Nitrogen is brought up as a high pressure gas in both the fluids rack and fluids pallet.

The philosopy for component sizing and configuration development is presented. This is followed by descriptions and criteria evaluations of each of the gaseous nitrogen system candidate configurations. The terms *configuration* and *option* are used interchangeably here since options are different versions of the same general configuration, only constituted by slight changes in the hardware or operation of a configuration. The discussion of potential liquid nitrogen systems is discussed in Section 6.5.6.3.

6.5.6.1 Component Sizing and Configuration Development - The sizing of nitrogen system components for the development of each configuration and its options is based on specific nitrogen storage and delivery conditions including hypothetical flowrates. Components are sized for spatial dimensions, masses, and the power requirements (if any) for power consuming delivery or transfer components. Estimates of the power to operate pumps, compressors, heaters, etc., for conditioning of the nitrogen were determined for the hypothetical flowrates derived. The interface requirements documents and information from the components data base were used to define the system hardware components.

The worse case nitrogen flowrates for a hypothetical usage scenario are determined for sizing of some of the system components. The supply subsystem scenario chosen for purposes of sizing nitrogen system components assumes constant usage by the ECLSS and allows the remaining nitrogen used over the period of a day to be delivered to users over a 5 minute duration. Although it is highly unlikely that a day's use of nitrogen will be consumed this quickly, it provides a basis with which to conservatively size components that are dependent on the mass flowrate of nitrogen. Sizing in this manner will allow the components to realistically accomodate any eventual increases in the demand for nitrogen, providing growth potential and operational flexibility. A total of 632 lbm of nitrogen for gaseous distribution will be delivered to users over any 90 day period. This corresponds to about 7.02 lbm/day, or a flowrate of approximately <u>30 lbm/hr</u> over the hypothetical <u>5 minute delivery period</u> for non-ECLSS nitrogen. Under normal usage conditions (non-emergency), this flowrate was used to size pumps, compressors and heaters for delivery of nitrogen to users.

A different flowrate is assumed for transfer resupply of nitrogen to the on-board storage subsystem. This flowrate is used to size transfer components such as transfer pumps and compressors. The flowrate is determined by transferring the 896 lbm of nitrogen required for emergency use over a full 7 day overlap period during which the NSTS shuttle is docked. The resulting flowrate is relatively small, about <u>5.33 lbm/hr</u>, as opposed to the 30 lbm/hr worse case rate for peak delivery to users. When compared to the average user flowrate of 0.30 lbm/hr (normal average of all user required gaseous nitrogen over 90 days), this rate is relatively high. More commonly, the transfer flowrate will amount to about <u>1.60 lbm/hr</u> when only contingency nitrogen is replaced due to a skipped cycle. The higher flowrate of 5.33 lbm/hr is used for sizing of transfer compressors.

Tank and pressure vessel volumes and the associated dimensions for a spherical geometry are determined from the expulsion efficiency computed for a given delivery scenario. A given delivery scenario consists of the initial and final tank conditions (pressure, temperature) and the thermodynamics involved with the supply of nitrogen. A blowdown system may deliver nitrogen isothermally if the use rate is slow or it may deliver the fluid isentropically where the use rate is very rapid and the fluid system can be assumed adiabatic. The actual delivery scenario will be somewhere between the isothermal and isentropic cases. The isentropic process will require a larger margin in the quantity of nitrogen because it becomes more difficult to acquire nitrogen isentropically due to rapid cooldown and condensation of the gas in the tank. The actual delivery scenario from the supply and storage subsystems will dictate the size of the tankage system and the fluid mass required to fill the system. Sizing was based on the isentropic delivery relationships of gaseous nitrogen. In the case of the supply subsystem, it is very important to know how much fluid is resupplied for launch purposes.

Nitrogen system pressure vessel masses for the high pressure gas supply systems were computed from a statistical performance factor relationship obtained from Structural Composite Industries[9]. The performance factor (PF) is defined as the product of burst pressure (BP, psia) and volume, (VOL, in^3) divided by the pressure vessel weight (WT, lb_f) as follows:

$$PF = \frac{BP * VOL}{WT}$$

From this relationship and knowing what the PF is for the pressure vessel material used, the pressure vessel weights were derived. The burst pressure is defined as twice the operating pressure and the performance factor was selected as 900,000, consistent with a spherical graphite composite pressure vessel with titanium liner.

Weights of corresponding spherical cryogenic pressure vessels (cryo-supercritical) and tanks (subcritical liquid) were determined by correlating tank volumes with shuttle PRSA cryo-supercritical tank data.

When sizing components such as pumps, compressors or fluid heaters, the worst case nitrogen flowrate of 30 lbm/hr is used for delivery sizing and 5.33 lbm/hr is used for nitrogen transfer hardware (compressors). These and other hardware items associated with each of the INS options are presented in tabular form in Table 6.5-1 which includes sizes, weights, power, and interface requirements. The table accompanies the following detailed descriptions of the nitrogen system configurations.

6.5.6.2 Nitrogen System Configurations

A. INS Configuration #1(Reference Configuration with High Pressure Gas Resupply) - Configuration #1 is a fully integrated gaseous nitrogen system that uses the high pressure gaseous (supercritical) method for resupply and storage. Figures D-1 and D-2 illustrate this configuration in detail without and with delivery compressors, respectively, and showing how each of the subsystems and their components are integrated with one another to form a fully integrated nitrogen system. Tables D-1 through D-4 list the components and requirements of the configuration options which are described here. A single supply subsystem pressure vessel was designed at IOC for this configuration. For the different options, pressure vessel sizes ranged from 3.5 to 4.4 feet in diameter for spherical tank geometries. This range of sizes is ideal for packaging and delivery aboard the Logistics Elements. A single tank system was developed at IOC since use of a multiple tank system at IOC just adds weight and is not necessary. The pallet design has the capability to add additional tanks as needed in the future when the resupply quantity of nitrogen eventually increases. A high pressure gas storage subsystem concept at 1,000 psia is employed as the Reference, however, the 5,000 psia storage subsystem pressure vessels are optimum in terms of life cycle cost (explained in Section 6.5.7, INS Storage Subsystem Tank Study). The same delivery and storage subsystem concepts are used with the cryo-supercritical and subcritical liquid supply subsystem concepts.

The blowdown transfer method of acquiring nitrogen from the supply and delivery subsystems is employed. This is the simplest process requiring a minimum of hardware and capable of providing a continuous supply of gaseous N_2 to users without sophisticated fluid control. It has its limitations, however, due to the fact that as the operating pressure of the system drops with time, the ability to supply higher flowrates diminishes.

Four nitrogen delivery scenarios were evaluated with this process, each of which is a nitrogen system option for Configuration #1. Two different resupply pressures are combined with compressed and non-compressed delivery capabilities to establish these options. The final supply pressure of the compressed options is resultingly lower since more nitrogen is obtained from the pressure vessels and compressed to a higher pressure.

The first two options (Options A and B) resupply gaseous nitrogen at a pressure of 3,500 psia and the last two options (Options C and D) resupply nitrogen at 8,000 psia. The 3,500 psia pressure is consistent with a pressure decided by NASA JSC to be a safe supply operating pressure. The higher initial operating pressure of 8,000 psia was arbitrarily selected to compare the advantages and disadvantages of a supply subsystem with a higher expulsion efficiency and higher potential for blowdown transfer. The higher pressure system has proved to be heavier and to pose safety concerns.

The four options developed from Configuration #1 are listed in Table 6.5-2. Options A and C

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Table 6.5-1 INS Configuration Matrix with System Specifications

INS Supply, Storage, and Delivery Hardware Inputs to Integrated Cost Model				Resupply/Supply Subsystem Parameters									Power Consuming Nitrogen Component Parameters**						
													Compressors		Pumps		Heaters		
	Config. # (Option #)	Description of Configuration (Option)	Type of System	# Supply Tanks	Tank Volume-ft^3	Tank Size, diameter -ft	Tank Weight -lbm	Nitrogen Resupply Qty. -lbm/90 days	User Qty. of Nitrogen -lbm/90 days	Deorbit Nitrogen -lbm/90 days	Tank System Weight-lbm*	# Storage Tanks	Peak Power-kW	Energy -kW-hr/90 days	Peak Power-W	Energy -kW-hr/90 days	Peak Power-kW	Energy -kW-hr/90 days	Total Energy Required -kW-hr/90 day***
1	1A	3,500 psia high pressure gas supply, no delivery compressors, transfer compressors required for Pstor > 3,000 psia	Fully-Integrated gaseous N2	1	44.44	4.39	597	693	632	61	1290	1	NO no delivery compressors	None	N/A	--	N/A	--	0 +
2	1B	3,500 psia high pressure gas supply, with delivery compressors, transfer compressors required for Pstor > 3,000 psia	Fully-Integrated gaseous N2	1	40.97	4.28	551	639	632	7	1190	1	2.63 used for delivery to users	1.01	N/A	--	N/A	--	1.01 +
3	1C	8,000 psia high pressure gas supply, no delivery compressors, no transfer compressors required for Pstor up to 7,000 psia	Fully-Integrated gaseous N2	1	24.13	3.59	741	665	632	33	1406	1	NO no delivery compressors	None	N/A	--	N/A	--	0 +
4	1D	8,000 psia high pressure gas supply, with delivery compressors, no transfer compressors required for Pstor up to 7,000 psia	Fully-Integrated gaseous N2	1	23.07	3.53	709	636	632	4	1345	1	2.63 used for delivery to users	0.57	N/A	--	N/A	--	0.57 +
5	2A	530 psia cryo-supercritical supply, no delivery compressors, transfer compressors absolutely required	Fully-Integrated cryogenic-supercritical N2	1	16.52	3.16	292	654.6	632	22.6	946.6	1	NO no delivery compressors	None	Tank recirculator pumps - negligible power use		1.13 1.30	9.10 tank 19.73 delivery	28.83 +
6	2B	530 psia cryo-supercritical supply, with delivery compressors, transfer compressors absolutely required	Fully-Integrated cryogenic-supercritical N2	1	16.01	3.13	284	634.5	632	2.5	918.5	1	2.63 used for delivery to users	0.4	Tank recirculator pumps - negligible power use		1.13 1.30	8.81 tank 19.12 delivery	28.33 +
7	2C	600 psia cryo-supercritical supply, no delivery compressors, transfer compressors absolutely required	Fully-Integrated cryogenic-supercritical N2	1	16.39	3.15	290	654.4	632	22.4	944.4	1	NO no delivery compressors	None	Tank recirculator pumps - negligible power use		1.13 1.30	9.24 tank 19.22 delivery	28.46 +
8	2D	600 psia cryo-supercritical supply, with delivery compressors, transfer compressors absolutely required	Fully-Integrated cryogenic-supercritical N2	1	15.89	3.12	283	634.5	632	2.5	917.5	1	2.63 used for delivery to users	0.39	Tank recirculator pumps - negligible power use		1.13 1.30	8.96 tank 18.63 delivery	27.98 +
9	2E	1,000 psia cryo-supercritical supply, no delivery compressors, transfer compressors required for Pstor > 1,000 psia	Fully-Integrated cryogenic-supercritical N2	1	15.84	3.12	305	653.6	632	21.6	958.6	1	NO no delivery compressors	None	Tank recirculator pumps - negligible power use		1.12 1.28	10.91 tank 16.78 delivery	27.69 +
10	2F	1,000 psia cryo-supercritical supply, with delivery compressors, transfer compressors required for Pstor > 1,000 psia	Fully-Integrated cryogenic-supercritical N2	1	15.38	3.09	298	634.4	632	2.4	932.4	1	2.63 used for delivery to users	0.38	Tank recirculator pumps - negligible power use		1.12 1.28	10.59 tank 16.29 delivery	27.26 +
11	3	20 psia subcritical LN2 supply, with delivery and transfer pumps, heaters used for tank and delivery nitrogen conditioning	Fully-Integrated subcritical liquid N2	1	13.65	3.00	256	645	632	13	901	1	NO no compressors at all	None	9.50 delivery, transfer pumps	0.20	1.58	33.3 tank and delivery	33.50 +
12	4A	3,500 psia high pressure gas pallet, 3,500 psia high pressure gas fluids rack for experiments, no delivery compressors, transfer compressors required for Pstor > 3,000 psia, fluids rack placement in USL with permanent distribution lines	Partially-Integrated gaseous N2	5 1	8.78 35.56	TBD 4.08	118 478	137 554.6	126 506	10.9 48.6	255 1032.6 1287.6	1	NO no delivery compressors	None	N/A	--	N/A	--	0 +
13	4B	8,000 psia high pressure gas pallet, 3,500 psia high pressure gas fluids rack for experiments, no delivery compressors, no transfer compressors required, fluids rack placement in USL with permanent distribution lines	Partially-Integrated gaseous N2	5 1	8.78 19.32	TBD 3.33	118 594	137 532.4	126 506	10.9 26.4	255 1126.4 1381.4	1	NO no delivery compressors	None	N/A	--	N/A	--	0 +
14	4C	3,500 psia high pressure gas pallet, 3,500 psia high pressure gas fluids rack for experiments, with delivery compressors, transfer compressors required for Pstor > 3,000 psia, fluids rack placement in USL with permanent distribution lines	Partially-Integrated gaseous N2	5 1	8.78 32.77	TBD 3.97	118 440	137 511.1	126 506	10.9 5.1	255 951.1 1206.1	1	2.63 used for delivery to users	0.81	N/A	--	N/A	--	0.81 +
15	4D	8,000 psia high pressure gas pallet, 3,500 psia high pressure gas fluids rack for experiments, with delivery compressors, no transfer compressors required, fluids rack placement in USL with permanent distribution lines	Partially-Integrated gaseous N2	5 1	8.78 18.46	TBD 3.28	118 567	137 508.9	126 506	10.9 2.9	255 1075.9 1330.9	1	2.63 used for delivery to users	0.46	N/A	--	N/A	--	0.46 +
16	4E	3,500 psia high pressure gas pallet, 3,500 psia high pressure gas fluids rack for experiments, no delivery compressors, transfer compressors required for Pstor > 3,000 psia, portable pressure vessels in modules, no permanent distribution	Partially-Integrated gaseous N2	5 1	8.78 35.56	TBD 4.08	118 478	137 554.6	126 506	10.9 48.6	255 1032.6 1287.6	1	NO no delivery compressors	None	N/A	--	N/A	--	0 +
17	4F	8,000 psia high pressure gas pallet, 3,500 psia high pressure gas fluids rack for experiments, no delivery compressors, no transfer compressors required, portable pressure vessels in modules, no permanent distribution	Partially-Integrated gaseous N2	5 1	8.78 19.32	TBD 3.33	118 594	137 532.4	126 506	10.9 26.4	255 1126.4 1381.4	1	NO no delivery compressors	None	N/A	--	N/A	--	0 +
18	4G	3,500 psia high pressure gas pallet, 3,500 psia high pressure gas fluids rack for experiments, with delivery compressors, transfer compressors required for Pstor > 3,000 psia, portable pressure vessels in modules, no permanent distribution	Partially-Integrated gaseous N2	5 1	8.78 32.77	TBD 3.97	118 440	137 511.1	126 506	10.9 5.1	255 951.1 1206.1	1	2.63 used for delivery to users	0.81	N/A	--	N/A	--	0.81 +
19	4H	8,000 psia high pressure gas pallet, 3,500 psia high pressure gas fluids rack for experiments, with delivery compressors, no transfer compressors required, portable pressure vessels in modules, no permanent distribution	Partially-Integrated gaseous N2	5 1	8.78 18.46	TBD 3.28	118 567	137 508.9	126 506	10.9 2.9	255 1075.9 1330.9	1	2.63 used for delivery to users	0.46	N/A	--	N/A	--	0.46 +

* Tank system weight includes the tank and nitrogen resupply weight
** Does not include transfer hardware specifications if components are required for the transfer of nitrogen to the Storage Subsystem
*** The '+' indicates additional energy is required to operate any Supply and Storage Subsystem tank heaters, and components for transfer to the Storage Subsystem in addition to the figures listed

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Table 6.5-2 INS Configuration #1 System Options (High Pressure Gas Resupply)

Configuration	Option	Initial Pressure - psia	Delivery Compressors (Y/N)	Final Pressure - psia	Expulsion Efficiency
1	A	3,500	N	250	91.2%
	B*	3,500	Y	20	99.0
	C	8,000	N	250	95.0
	D	8,000	Y	20	99.4

* Reference Configuration

(3,500 and 8,000 psia supply, respectively) blow down the supply subsystem tank(s) from the initial operating pressure to a final tank pressure of 250 psia before resupply is necessary. These options, shown in Figure D-1, use no compressors for delivery of gaseous nitrogen. The 250 psia final pressure is the minimum delivery pressure required by users as an interface requirement[1]. The need for compressors to deliver nitrogen to users is negated since the blowdown pressure is always greater than or equal to the minimum delivery pressure. Options B and D (3,500 and 8,000 psia supply, respectively) blowdown the supply subsystem tank(s) from the initial operating pressure to a final tank pressure of 20 psia before resupply. These options are shown in Figure D-2. In these cases, compressors for delivery of nitrogen to users will be required when the tank pressure is below 250 psia, at which time delivery changes from blowdown to compressed delivery. The difference between these two pairs of configuration options lies in the cost of either launching or deorbiting residual nitrogen or the cost involved with developing, delivering, operating, and maintaining compressors for delivery of nitrogen. The cost model assessment presented in Section 6.5.8 will shed light on these differences. Since a higher expulsion efficiency can be obtained when delivery compressors are used, a much lower quantity of residual nitrogen will result, and the resupply quantity will be reduced.

Advantages and disadvantages of these options are discussed here. Where disadvantages in the issues surrounding the configuration exist, proposed solutions are provided to possibly eliminate the associated problem from that system.

The safety issues that exist with high pressure vessels are a concern. While an intermediate pressure resupply vessel (3,500 psia) may possess merit by being more safe, it will not achieve the expulsion efficiency attainable with a higher pressure vessel (8,000 psia). The higher pressure supply subsystem requires lesser initial nitrogen resupply and leaves less residual fluid for deorbit. However, a high pressure supply subsystem tends to weigh more than an intermediate pressure system. In terms of launch weight, the difference in supply subsystem mass is much greater than the reduction in resupplied nitrogen.

When it comes to the efficiency involved with blowdown transfer from the supply to the storage subsystem tanks, an 8,000 psia supply vessel will blowdown with a higher expulsion efficiency and obtain more nitrogen from a single tank. Therefore, a fewer number of tanks will therefore have to be resupplied for transfer and repressurization when 8,000 psia supply vessels are used instead of 3,500 psia pressure vessels. This assumes that transfer is accomplished by blowdown and that no transfer compressors are used. If transfer compressors are used for compressed transfer, the resupply quantity, in terms of number of tanks, will be the same since identical amounts of nitrogen may be obtained from each resupply tank. No difference in the logistics of resupply will be noted.

Even though the higher pressure vessel can be built to the same safety standards as the intermediate pressure vessel, it has associated with it a potential safety risk. Component failure which results in either escaping high pressure gas of catastrophic failure or burst may present a risk to space station elements, systems, or space station personnel. Some of this risk may be mitigated for the safety of space station personnel in the modules by keeping high pressures from the supply and distribution subsystems external to the pressurized portions of the station. High pressure supplies will be regulated outside of the pressurized portions of the station to satisfy this goal.

For options with and without delivery compressors, a tradeoff exists between the costs of an increased nitrogen resupply quantity (without compressors) and the development and maintenance of space-qualified gas compressors. The residual fluid mass will be very small when delivery compressors are used since the expulsion efficiency is significantly enhanced. Compressors will make a difference in the quantity of residual nitrogen deorbited to earth each resupply period, but their development and operational costs may not be reduced enough to make up the difference in resupply cost savings.

In the cost assessment made on the nitrogen systems, the costs for compressor development versus the changes in nitrogen resupply costs are discussed in Section 6.5.8.

B. <u>INS Configuration #2 (with Cryogenic-Supercritical Resupply)</u> - Configuration #2 is also a fully integrated nitrogen system. It is similar to the high pressure gaseous Reference Configuration in that it incorporates the same storage and distribution subsystems. However, it employs the cryogenic-supercritical resupply/storage method as the supply subsystem (Alternate Resupply/Storage Concept 1, Section 6.5.1.2). Figures D-3 and D-4 illustrate this configuration without and with delivery compressors. Tables D-5 through D-10 list the components and requirements of the configuration options which are described here.

Major differences in hardware over the high pressure gas concept include vacuum-jacketed tanks, heaters, recirculator pumps, tank dispersion or mixing nozzles for tank conditioning, and delivery heaters for nitrogen temperature conditioning to meet user requirements. Mixing nozzles inside the pressure vessel insure nitrogen fluid homogeneity for fluid management by preventing stratification of the fluid into liquid and vapor components. The cryogenic-supercritical pressure vessel designs are much smaller and vacuum-jacketed for isolation of the nitrogen contents from the outside environment. A control system of sorts for tank conditioning is employed with primary pressure control and secondary temperature control.

Nitrogen, initially as a dense fluid, is delivered through a constant pressure blowdown transfer process above the critical pressure of nitrogen (P_c = 493 psia). With the expulsion of nitrogen, the tank must be heated to maintain the supercritical pressure and prevent condensation of the fluid. During nitrogen acquisition or use, the blowdown process will extend from one in which N_2 is blown down as a cryogenic fluid to one in which gaseous N_2 is blown down when the tank temperature exceeds the critical point for nitrogen. When the tank temperature reaches nominal temperature, the nitrogen will be allowed to blow down until the final pressure is attained. The cryo-supercritical supply subsystem pressure vessels operate initially in the cryogenic region and eventually become a supercritical gas.

Six nitrogen delivery scenarios operating at three supercritical pressures were examined. Each scenario is a fully integrated INS option for the cryogenic-supercritical supply concept. The six options that will be evaluated are listed in Table 6.5-3, listing the initial and final tank pressures, and the applicability of delivery compressors. It should be noted that for the lower pressure opions (Options A through D at 530 and 600 psia), transfer compressors for storage subsystem pressurization to 1,000 psia or higher are required. The 530 psia options (Options A and B) have enough pressure margin over the supercritical pressure so that for typical N_2 usage rates, the tank pressure should not drop below the critical pressure. The 600 psia pressure (Options C and D) is a level proposed by NASA JSC for a cryo-supercritical INS. Finally, the higher pressure options

Table 6.5-3 INS Configuration #2 System Options (Cryo-Supercritical Resupply)

Configuration	Option	Initial Pressure - psia	Delivery Compressors (Y/N)	Final Pressure - psia	Expulsion Efficiency
2	A	530	N	250	96.5%
	B	530	Y	20	99.6
	C	600	N	250	96.6
	D	600	Y	20	99.6
	E	1,000	N	250	96.7
	F	1,000	Y	20	99.6

at 1,000 psia (Options E and F) are consistent with a pressure that could conceivably eliminate transfer compressors when repressurizing storage subsystem tanks to 1,000 psia.

The tankage and fluid masses for cryo-supercritical options are considerably less than the high pressure gas concepts. This difference varies between 200 to 400 lbm when comparing certain options between the high pressure gas and cryo-supercritical configurations (see Table 6.5-1 and Tables D-1 to D-10 in Appendix D). This may provide a sufficient savings in launch costs to offset the higher development and maintenance costs associated with cryogenic-supercritical system components over the Space Station life.

The hardware intensiveness and increased demand for electrical power are far greater in the cryogenic-supercritical configuration than in the Reference high pressure gas system. Many more types of hardware are needed for system operation that are not needed by the high pressure gas supply systems. The number of components required for redundancy and spares for maintenance involved could become a severe disadvantage for implementation of such a system, because they may jeopardize the system's weight advantage over the less complex though heavier high pressure gas configuration. Also, component power requirements for this system can become quite substantial over the Space Station life, whereas the need for power to operate a high pressure gaseous blowdown type system is essentially nonexistent.

C. INS Configuration #3 (with Subcritical Liquid Resupply) - The last of the fully integrated configurations is Configuration #3. This configuration uses the same storage and distribution subsystems as the first two configurations but employs a self-packaged subcritical liquid nitrogen fluid resupply/storage concept (Alternate Resupply/Storage Concept #2, Section 6.5.1.3) as the supply subsystem to supply gaseous nitrogen to users. Figure D-5 in Appendix D illustrates how this supply subsystem concept is designed and interfaces the distribution and storage subsystems. Table D-11 lists the components and their requirements for this system.

This resupply concept differs from both the high presssure gas and cryo-supercritical concepts in its hardware makeup and the control and monitoring functions. Differences in hardware from the other concepts include a liquid acquisition device, acquistion (delivery) pumps, and a tank pressurization system. The tank pressurization system could possibly consist of an autogenous pressurization system or the option to use a pressurized gas source such as helium. The autogenous pressurization concept is depicted in the configuration schematic of Figure D-5 (previously shown in Figure 6.5-3). The helium pressurization concept was shown previously in Figure 6.5-4. Autogenous pressurization may not be possible without the use of a thermodynamic vent system (TVS) tank heat exchanger to subcool the nitrogen for acquisition. A vapor vent system or VCS system may still aid in the guard against environmental heat leak and vaporization of liquid. Thermal insulation such as MLI may also be necessary to reduce the amount of heat leak into the tank. The subcritical liquid tank design is smaller in size and less in mass than all of the other systems evaluated. It also requires a vacuum jacket similar to the cryogenic-supercritical design. A control system with primary pressure control and feedback to the tank pressurization system and secondary temperature control and feedback to the pressurization system is necessary to insure positive head for pumping the liquid from the tank.

Only a single option for the subcritical supply subsystem configuration was considered. Table 6.5-4 lists the single option developed and evaluated. Operating conditions maintain the nitrogen at saturated temperature conditions with a slight overpressure for acquisition of the liquid. This configuration will require further development before its implementation since the technology is only now being developed to solve the problem of venting in a low-g environment. This technology will eventually be required to readily implement proven LN_2 supplies in support of liquid nitrogen needs, i.e. liquid for cooling in the USL. System control and management functions are complex, probably adding little merit either from operational or cost standpoints. This system also demands the greatest in electrical power requirements, exceeding the power required by cryo-supercritical components by 20%, although power availability and cost on this level will not be a major factor in the decision of an optimal INS configuration.

Table 6.5-4 INS Configuration #3 System Options (Subcritical Liquid Resupply)

Configuration	Option	Initial Pressure - psia	Delivery Compressors (Y/N)	Final Pressure - psia	Expulsion Efficiency*
3		20	No, pumps used	20	98.0%

* typical expulsion efficiency of liquid nitrogen tank

The liquid nitrogen required by the USL is not integrated with the INS system examined here that delivers gaseous nitrogen to Space Station users. It is extremely difficult to effectively integrate a nitrogen system that includes the supply of gaseous and liquid nitrogen to users from a common supply source. Such a system is more easily designed to supply the liquid nitrogen requirements for the Space Station from an independent dedicated system. In this study, the system that supplies liquid nitrogen to the USL for cooling is treated as an independent system dedicated to that cause. The current liquid nitrogen resupply configuration presented here for the purpose of supplying gaseous nitrogen to users could potentially be integrated with the liquid nitrogen interfaces in the USL, but would be ideal only in instances where a large LN_2 demand or multiple LN_2 users exist. Again, section 6.5.6.3 goes into depth on the recommended LN_2 configuration for the Space Station and the practicality of integrating the LN_2 system with the currently developed gaseous INS systems.

D. INS Configuration #4 (Dedicated Gaseous Storage for Experiments) - Configuration #4 is a partially integrated gaseous nitrogen system that dedicates a high pressure gas fluids rack to some of the users, i.e. the experiments, and integrates a high pressure fluids pallet with the ECLSS and remaining users. Approximately 20% of the nitrogen resupply quantity for gaseous delivery is dedicated to the experiments while the remaining 80% is occupied in the external fluids pallet. The general configuration schematics are shown in Figures D-6 and D-7, illustrating the two options that were developed. Each option entails a different use scenario for the nitrogen brought up in fluids racks. Figure D-6 depicts the fluids rack(s) being brought up in the Pressurized Logistics Carrier (PLC) and moved to a location in the USL. The gaseous nitrogen is distributed through a distribution system permanently installed throughout the modules. Figure D-7 depicts the fluids rack(s) placed in the USL, with distribution of portable pressure vessels (PPV's) to the individual modules. This concept alleviates the permanent lines and penetrations through the nodes and modules. Distribution in the modules is accomplished by using flexible lines from PPV('s) to the experiments, or by running distribution systems in the modules that interface the experiment racks (shown in the figure).

This configuration slightly complicates the logistics involved with resupply of the required nitrogen. Both the PLC and the Unpressurized Logistics Carrier (ULC) are required for resupply of the total nitrogen quantity for gaseous users. And, as a result, both Extra-Vehicular Activity (EVA) and Intra-Vehicular Activity (IVA) is necessary to handle the respective payloads. The additional maintenance activity resulting from the use of multiple supply systems becomes very costly. Any dedicated fluids racks are brought up by the PLC and transferred to the experimental modules during IVA operations. The external fluids pallet is brought up by the ULC and installed at the interface locations on the Space Station outside of the modules during EVA operations.

A nitrogen system dedicated to specific users will not be advantageous due to additional hardware and maintenance requirements. Already there is more than one supply subsystem brought up by the Logistics Elements. This alone will cost substantially more than a single supply subsystem. Furthermore, additional plumbing, valving and pressure regulating hardware components are necessary for control of each system, adding to the initial hardware procurement costs and overall maintenance efforts.

A dedicated nitrogen system is ideal for a few reasons. Where the nitrogen requirements for experiments are not very well known and the use of such nitrogen has the potential to fluctuate from one resupply period to another, a dedicated supply for experiments may be a viable alternative to over-supplying with a single resupply system. A fluids rack(s) may be supplied to the station with more than a 90 day resupply of experimental nitrogen and left until all nitrogen is used. This would eliminate under- or over-supplying of nitrogen for an integrated supply subsystem pallet (fully integrated system). This system would also eliminate the associated increase in launch and deorbit costs of large residual nitrogen quantities if less than an average amount of experiment nitrogen is used over a 90 day period by eliminating any ambiguities in the amount of nitrogen that would need to be supplied in a single pallet. The fully integrated system may be able to facilitate such uncertainties in the resupplied nitrogen quantity by allowing for all of the useable nitrogen from a pallet to be used before it is deorbited. A currently tapped pallet would be left at the station until its nitrogen is gone before tapping the new supply pallet. This would involve leaving a pallet at each supply subsystem interface location over a resupply period so that the partially empty pallet from the previous resupply period may be used up. Tapping of the newly resupplied pallet would occur upon depletion of the first pallet. Although this requires the construction of one additional resupply pallet as a spare, this cost is easily recovered over the life of the Space Station since the quantity of deorbited nitrogen will undoubtedly be reduced.

The operational specifications of each of eight options developed as dedicated gaseous systems (partially integrated) are listed in Table 6.5-5. The components and requirements lists for the options are listed in Tables D-12 to D-19 in Appendix D. Options A through D are systems that use fluids racks in the USL for the supply of N_2. The differences in the options are variations in the operating pressure of the resupply pallet and whether or not compressors are required for nitrogen delivery. Options E through H are systems that use PPV's in the modules for the same combinations of supply pressure and compressor options. All fluids rack supplies are brought up to the Space Station at 3,500 psia, above which is considered too hazardous to occupy space with the occupants of the modules and below which would be innefficient for resupply.

6.5.6.3 Liquid Nitrogen Configuration Options - The development of a liquid nitrogen system to satisfy the user demands of LN_2 for cooling in the USL at IOC is of relatively major concern. Not only will the USL need nitrogen as a liquid, but virtually every laboratory or operation aboard the Space Station will eventually have some need for an LN_2 supply. The system designed to deliver liquid nitrogen to the USL users could either be integrated into one of the fully integrated N_2 systems for gaseous N_2 delivery or it could be an independently dedicated LN_2 system where LN_2

Table 6.5-5 : INS Configuration #4 System Options (Dedicated High Pressure Gas Resupply)

Configuration	Option	Initial Pressure - psia	Delivery Compressors (Y/N)	Final Pressure - psia	Expulsion Efficiency*
4	A	3,500	N	250	91.2%
	B	8,000	N	250	95.0
	C	3,500	Y	20	99.0
	D	8,000	Y	20	99.4
	E	3,500	N	250	91.2
	F	8,000	N	250	95.0
	G	3,500	Y	20	99.0
	H	8,000	Y	20	99.4

* expulsion efficiency of Fluids pallet for ECLSS

is brought up in liquid dewars for the sole purpose of supplying LN_2 for specific users in the USL. Although it is very much a possibility to integrate the gaseous and liquid N_2 requirements into a fully integrated system, lack of requirements definition as to the number of users, the N_2 use rates, and the length of plumbing, etc., may limit its practicality and render a locally dedicated system a more practical choice. It is therefore recommended that LN_2 be dedicated to the USL, at least for IOC. Practical considerations of this and of integrated options are discussed.

Since all users of liquid nitrogen at IOC are currently aboard the USL, even though the required quantity is relatively large (608 lbm every 90 days), a dedicated supply for the USL may be brought up via the PLC. This is justified since all LN_2 users are closely located to one another in the USL at IOC where single or multiple dedicated LN_2 dewars will handsomely accomodate the users. For these reasons, it is unnecessary to integrate the LN_2 system with other elements of the Space Station until further requirements definition dictates. Figure 6.5-6 illustrates how LN_2 dewars supply nitrogen as a liquid to USL users. The resupply system is composed of an LN_2 dewar with a pressurization system, and possible internal submersible pumps for LN_2 acquisition. This dewar resupply/supply system will interface with the USL at independent USL rack locations or through a vacuum-jacketed and insulated LN_2 distribution system. Examples of both options are shown in the figure.

If the demand for LN_2 becomes very substantial or the number of LN_2 users increases or spreads to the other Space Station elements, the application of independent dewar systems for users or elements may become cumbersome and inconvenient. A more viable approach may be to integrate an LN_2 system on either a partially or fully integrated system level. In consideration of all gaseous and liquid N_2 users, a totally integrated system would entail the integration of a single N_2 supply for for all gaseous and liquid requirements. A partially integrated system in the same context might consist of one system integrated for all gaseous N_2 users and single or multiple systems dedicated to liquid users. The currently specified LN_2 system for the USL is a partially integrated system dedicated to the USL only. A single LN_2 supply system could be integrated for all LN_2 users if those users are spread throughout more than one of the Space Station elements.

A system that totally integrates all gaseous and liquid N_2 requirements could be developed into a single subcritical liquid supply concept, with a few critical concerns. In this concept, LN_2 could be supplied as needed from the supply subsystem and any gaseous nitrogen required would simply be heated and compressed for use. The real technical implications involved with such a system relate to the transfer, storage, and conditioning of LN_2 as it is distributed through the plumbing to insure that N_2 still arrives at the user interfaces as a liquid. The length of the distribution system and the degree of thermal isolation afforded directly affects the state at which

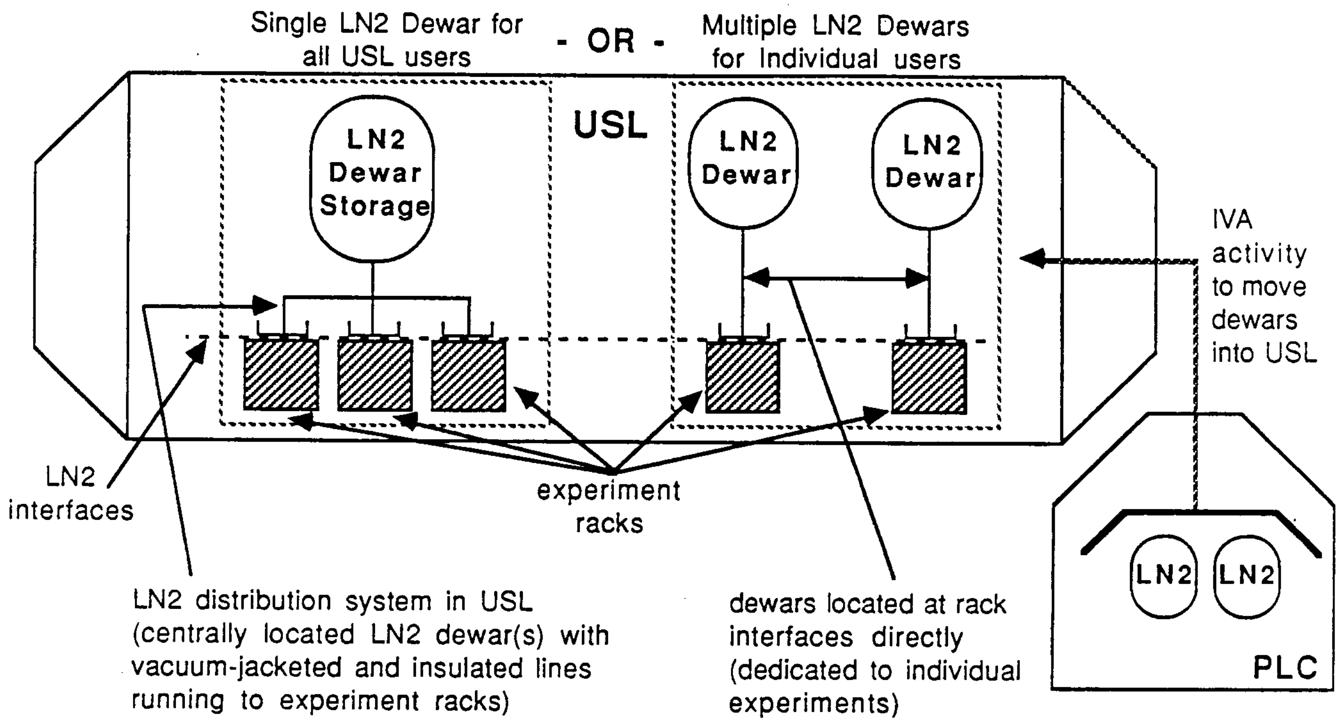

Figure 6.5-6 Supply of LN_2 Dewars for Liquid Nitrogen Requirements in the USL

nitrogen initially supplied as a liquid finally reaches the user interfaces. Long distribution systems and severe thermal environments without high performance insulation may allow the LN_2 to warm to the point of becoming a two-phase fluid or gas before it reaches an LN_2 user. Intermediate cooling steps could be employed to help alleviate any problem of this sort. This is one of the reasons that provides the basis behind local dedication of LN_2 dewars.

A method by which the problems of LN_2 vaporization could be eliminated is the alternative of a no-vent fill process that transfers LN_2 to intermediate storage dewars strategically located at or near the user interfaces. This configuration is highly practical where multiple users requiring multiple independent dewars for LN_2 support exist and where it would be impractical to change out this many single units. Multiple dewars would be installed at independent user interfaces and filled through an interface connected to the supply subsystem storage media via this no-vent fill process. LN_2 could be rapidly transferred with a minimum of parasitic heat leak. This alternative provides an attractive advantage over a system where LN_2 is transferred directly from the primary supply to the user interface at relatively slow rates, allowing the LN_2 to heat up. There are problems that reside with this system, particularly with the need to vent the tanks prior to fill or venting during the fill process itself. A no-vent fill process may not be possible since incoming warm LN_2 may cause excessive pressure to build up in the tanks. Accomodations for venting may become a requirement if this system is going to be used.

Certainly, it is not very practical in terms of cost and fluid management functions to totally integrate liquid and gaseous nitrogen users where N_2 may be supplied as a gas or cryo-supercritical fluid. If gas or cryo-supercritical fluid were resupplied, steps would have to be taken to re-liquify gaseous nitrogen to a liquid. The re-liquification process would be complex and power intensive. These steps would be unnecessary if N_2 was resupplied as a liquid. However, in the event that a totally integrated system is required or desired and LN_2 system technology is not fully adaptable to the Space Station, this may be the only possible means.

6.5.7 INS Contingency Storage Subsystem Tank Study

A series of Integrated Nitrogen System Contingency Storage Subsystem options were developed and evaluated in terms of their commonality and integration with the overall gaseous nitrogen system. The Storage Subsystem design was groundruled to use high pressure gas vessels for the storage of emergency and contingency nitrogen. This is the simplest and most efficient design for long-term storage of nitrogen, requiring only minimal fluid conditioning. Due to the potential for long-term storage, it is highly impractical to store nitrogen as a cryogen on-board the Space Station.

A parametric study was performed, varying the maximum operating pressure of the storage subsystem and evaluating the tradeoffs existing for the resulting pressure vessel sizes, weights, and the tank performance levels that result with the capability to deliver the full amount of emergency and contingency nitrogen. The tank performance levels were evaluated in terms of expulsion efficiency, nitrogen delivery rate, and the methods of transfer resupply (repressurization) from the supply subsystem to the on-board storage subsystem pressure vessels. These items were used to determine the feasibility and practicality of integrating a particular storage subsystem pressure vessel design into the INS.

6.5.7.1 Storage Subsystem Sizing - Pressure vessels were sized for a given maximum operating pressure (full pressurized condition) assuming blowdown delivery from the maximum pressure down to the minimum required delivery pressure of 750 psia at a nominal temperature of 70°F as required for cabin control. The 750 psia pressure is the minimum requirement for delivery of emergency nitrogen[2] to the ECLS system. The pressure vessels will be capable of delivering *all* of the contingency and emergency nitrogen at a pressure of 750 psia or above on demand, and to do so without the need for gas compressors. Small pressure vessel heaters within the tanks are employed to maintain tank temperatures in conjunction with the use of tank insulation to minimize parasitic heat loss. Table 6.5-6 below lists the specifications of the storage subsystem options; the pressures considered, and the tank and fluid parameters developed in the study such as sizing, tank mass, performance, and nitrogen fill quantity information resulting from the given supply and delivery conditions imposed on the system. Tables D-20 through D-24 in Appendix D list the components of each storage subsystem option.

Table 6.5-6 Storage Subsystem Option Sizing Specifications

			Masses - lbm				
Operating Pressure-psia	Volume -ft^3	Vessel Diam-ft	Tank Only	GN2	Tank+ GN2	Residual GN2	Expulsion Efficiency
1,000	848.8	11.75	3,259	4,200	7,459	3,304	21.3%
1,500	282.3	8.14	1,626	2,080	3,706	1,184	43.1
2,000	168.4	6.85	1,293	1,633	2,926	737	54.9
3,000	98.05	5.72	1,130	1,370	2,500	474	65.4
4,000	71.69	5.15	1,101	1,265	2,366	369	70.8
5,000	58.45	4.82	1,122	1,213	2,335	317	73.9
6,000	50.61	4.59	1,166	1,183	2,349	287	75.7
7,000	46.01	4.45	1,237	1,164	2,401	268	77.0
8,000	41.53	4.30	1,276	1,145	2,421	249	78.3

C-2

The maximum operating pressure of the Storage Subsystem options in the trade study varied from 1,000 to 8,000 psia, typical of a wide range of values that might possibly be used for on-board storage of nitrogen. The 1,000 psia level is probably a minimum level whereby the storage subsystem pressure vessels could potentially deliver nitrogen in emergency situations and maintain adequate flowrates for a minimum delivery pressure of 750 psia. The intermediate and high pressure options were arbitrarily selected to be consistent with the levels evaluated for the high pressure gas supply subsystem options.

The tank sizes, weights and nitrogen fill quantities vary widely over this range of pressures. Since the differential pressure for blowdown becomes less when the storage subsystem pressure is less, the low pressure vessels have to occupy much larger volumes to deliver the required nitrogen. This is evident by the fact that expulsion efficiencies are lower for smaller differential pressures, thus demanding higher nitrogen fill quantities. The higher nitrogen fill quantities are only noticed when initially brought up by the logistics system at IOC. Following the initial launch, only quantities for replenishment are resupplied and not the entire fill quantity. Although these large nitrogen fill quantities affect the cost of implementation of the storage subsystem to very little degree, the large tank designs associated with low pressure systems constitute much higher costs for procurement, launch, and maintenance. The lower pressure designs do, however, reduce the likelihood that transfer resupply compressors will be required and thus reduce the number of supply pressure vessels required to facilitate their repressurization (transfer resupply methods and requirements presented in Section 6.5.7.2). As the operating pressure of the storage subsystem pressure vessels is increased, tank sizes decrease substantially and level out to just above 40 ft^3 of volume at 8,000 psia of pressure.

Spherical pressure vessel sizes become more realistic where packaging and transport in the Logistics Carriers is concerned when the pressure reaches levels of 3,000 psia or higher. The diameter of a 3,000-4,000 psia pressure vessel is around 5-6 ft. and that of an 8,000 psia pressure vessel is just over 4 ft. in diameter (see Table 6.5-6). Figure 6.5-7 illustrates the trends in the tank and nitrogen weights for the storage subsystem options. The tank weights are extremely high at 1,000 psia due to their size, rapidly falling to a minimum at around 3,000-4,000 psia, and rising again at a slow rate since a tradeoff exists between thicker pressure vessel designs while their physical size becomes smaller. The minimal system weight (tank + nitrogen) occurs at around 5,000 psia. The minimum cost design lies around 5,000 psia where the tank and nitrogen weight is minimum.

6.5.7.2 Resupply of Storage Subsystem Pressure Vessels - The storage subsystem pressure vessels must be resupplied with nitrogen when some or all of their reserve is used for emergency or contingency. There are a couple of methods whereby resupply of the storage subsystem pressure vessels is facilitated. Resupply may be performed by transfer from the supply subsystem or by trading out storage subsystem pressure vessels. The latter is EVA labor intensive and is not considered a viable alternative. From the supply subsystem, transfer resupply is accomplished by blowdown transfer repressurization if the operating pressure of the supply subsystem is higher than the operating pressure of the storage subsystem, or by compressing nitrogen gas (especially for the cryogenic supply systems where the operating pressures are low) back into the storage subsystem pressure vessels via the use of compressors. The tanks that are at higher pressure for resupply drive a blowdown transfer and repressurization process for the storage subsystem pressure vessels. The process ceases once the pressure of the supply and storage subsystems equalizes. The number of tanks required for blowdown repressurization will depend on the amount of nitrogen needed for resupply and the differential pressure between the supply and storage subsystem tanks. With this methodology, a 3,500 psia supply tank can efficiently repressurize resupply storage vessels at lower pressures, however blowdown repressurization becomes inefficient if 3,500 psia tanks repressurize a 3,000 psia system due to lower differential pressure. Once the pressure in the source and target tanks equalize, another fully pressurized tank may be used to further pressurize the system.

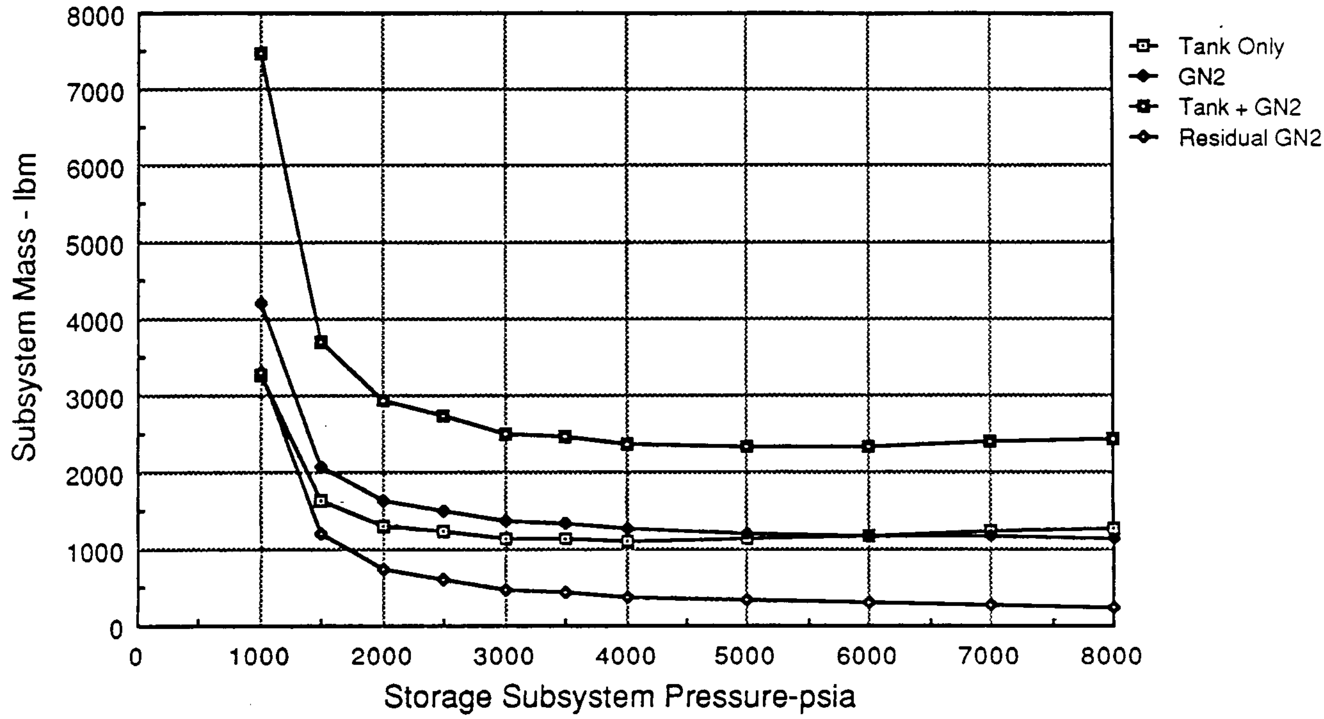

Figure 6.5-7 Contingency Storage Subsystem Tank and Nitrogen Masses

Another method by which storage subsystem pressure vessels may be resupplied is independent of the type or operating pressure of the nitrogen supply subsystem tanks. This method uses compressors to compress gaseous nitrogen from the supply subsystem to the final target pressure in the storage subsystem. This method may be applied to reduce the number of high pressure gas supply subsystem tanks (that would have normally been used for blowdown transfer) for transfer resupply of the storage subsystem by increasing the useable mass fraction of nitrogen. This alternative is absolutely required for the cryogenic-supercritical and subcritical liquid nitrogen supply options and is suitable for the high pressure gas options when compressors are desired or already in use for delivery of nitrogen to users. Commonality is enhanced since the same supply subsystem tank design is used for the resupply of nitrogen to the Space Station for transfer of N_2 to the storage subsystem.

Figure 6.5-8 illustrates how many 3,500 psia high pressure gas vessels (Configuration 1B-Reference Configuration) are needed for resupply of either the full or more commonly anticipated skip cycle (contingency) nitrogen quantities for single and cascade tank blowdown transfer to the storage subsystem. Storage subsystem options between 1,000 and 3,000 psia are considered. Superimposed on the figure is the fixed number of supply pressure vessels required to repressurize the storage subsystem tanks when compressors are used for transfer repressurization. These numbers, which are 1.42 and 0.43 tanks for total storage subsystem repressurization (emergency and contingency nitrogen) and for the contingency nitrogen repressurization (skipped cycle), respectively, are much lower than blowdown transfer requirements in terms of the number of tanks. Transfer requirements in terms of the number of tanks becomes more evident as the storage subsystem pressure increases and the differential pressure between supply and storage is reduced. Note how single tank transfer is more efficient and requires a lesser number of transfer resupply tanks, especially at higher storage subsystem pressures where the differential pressure from supply to storage is less. The same results can be easily computed for any combination of the supply and storage subsystem concepts.

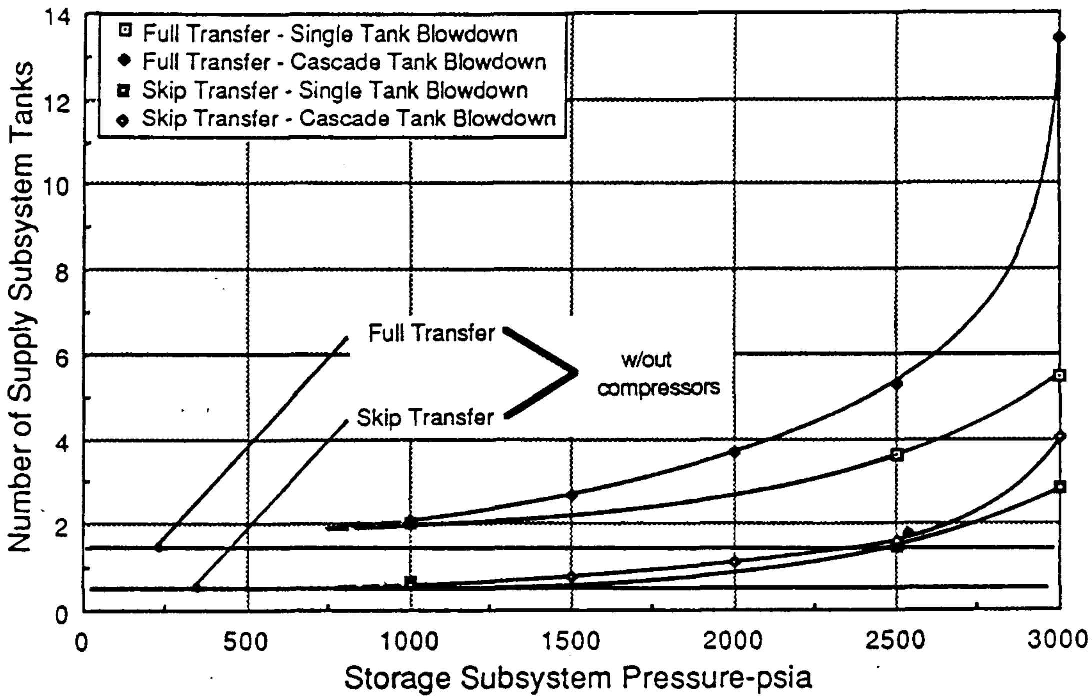

Figure 6.5-8 Supply Subsystem Requirements for Transfer Resupply (from 3,500 psia Gaseous Supply Subsystem Pressure Vessels, Option 1B)

A final option might be to develop a high pressure gas pressure vessel designed just for the purpose of storage subsystem blowdown transfer resupply. The higher the pressure this vessel is designed for, the lesser number of tanks that will be required to accomplish this task.

The cost model was used to evaluate the candidate INS systems with the 1,000, 3,000, and the 7,000 psia storage subsystem options. The 1,000 psia storage subsystem option is the Reference option (listed in the system component lists), the 3,000 psia option was indicative of an intermediate pressure level and indicated as the "(a)" option with the configuraion in the cost study, and the 7,000 psia option was a high pressure level for the storage subsystem and indicated as the "(b)" option (see Section 6.5.8, INS Integrated Cost Model Assessment). The 3,000 and 7,000 psia options were chosen to be analyzed in conjunction with the overall INS systems because they allow the 3,500 and 8,000 psia high pressure gas supply options to transfer nitrogen by blowdown transfer to the storage subsystem pressure vessels.

Knowledge of the frequency at which transfer resupply will take place (logistics) will aid in the selection of a particular storage subsystem. More information on the number of suspected storage subsystem resupply operations is necessary to evaluate whether or not it is more feasible to implement a storage subsystem that is more easily resupplied (a lower pressure, larger sized system) or a system that is smaller, weighs less, and is packaged in the logistics carrier more efficiently (higher pressure design). In certain instances, a compromise may be made regarding the best storage subsystem for a particular INS option depending on the specifications of the supply subsystem and the applicability of compressors to that system. For instance, a smaller, lighter weight 3,000 psia storage subsystem may prove ideal with a 3,500 psia high pressure gas supply subsystem concept when compressors are used for delivery because the same compressors may be used for compressed transfer (if sized for transfer) to the storage subsystem tanks rather than resupplying numerous supply subsystem pressure vessels at 3,500 psia for blowdown transfer. On the other hand, if it is anticipated that storage subsystem resupply becomes more frequent due to a high frequency of skipped cycles, it may be more advantageous to use a lower pressure storage subsystem design that reduces the effort for storage subsystem resupply. For an unknown storage subsystem resupply scenario, it is suggested that a compromise between resupply effort, system weight (cost), and the logistics of resupply (frequency of resupply and the optimum numbers and sizes of tanks for packaging) be made. Then, a decision on the optimal option for any given INS configuration may be made. In the case of the Space Station where no statistical data is yet available from its operation, this compromise may be difficult to make.

A preliminary cost model assessment was performed on the storage subsystem options outlined in Table 6.5-6. The cost model assessment for the INS candidate configurations as a whole are discussed in the next section, Section 6.5.8. The cost model results indicated the IOC, operating, and total life cycle costs for each option and the percent difference in LCC for each from the 1,000 psia Reference option. Table 6.5-7 lists the results showing that the lowest weight system at 5,000 psia costs the least. The cost is not much below the other relatively high pressure options (above 2,000 psia), however. Between 1,000 and 2,000 psia, the total system cost varies dramatically since the size of the pressure vessels at 1,000 psia is large. Due to the fact that the higher pressure options are so close to one another in cost, cost is not a major driver in selection of the most attractive system, but rather the compatibility of a particular option with the supply subsystem. For example, although the 5,000 psia option is the lowest cost, it is impossible to perform blowdown transfer from a 3,500 psia supply subsystem.

Table 6.5-7 Storage Subsystem Cost Study Results

Pressure - psia	Option #	IOC	Cost - $M Operating	Total	% Difference in LCC*
1,000	1	72.16	16.95	89.12	-0- %
1,500	2	40.42	9.13	49.55	-44.4
2,000	3	33.99	7.66	41.65	-53.3
3,000	4	30.51	6.95	37.46	-58.0
4,000	5	30.03	7.12	37.15	-58.3
5,000	6	29.24	6.93	36.16	-59.4
6,000	7	29.39	7.12	36.50	-59.0
7,000	8	29.86	7.43	37.29	-58.2
8,000	9	30.05	7.60	37.65	-57.7

* percent difference from 1,000 psia storage subsystem Option #1 (Reference)

6.5.8 INS Integrated Cost Model Assessment

An integrated cost model assessment was performed on the above candidate INS system configurations using the Integrated Cost Model developed under Task I of this program. The results of the cost model study are presented. A Life Cycle Cost analysis was conducted for purposes of identifying systems that are the lowest cost systems over a life cycle. Factors included in the cost study include recurring and non-recurring hardware and wraparound costs, initial fluid, launch, fluid resupply, spare parts, maintenance and deorbit (waste return) costs. All together, these cost items make up the overall IOC and operating costs of a system for a life cycle of 10 years.

The cost model assessment was used to evaluate the 19 gaseous INS options, each with three different storage subsystem options (total of 57 cases). The storage subsystem options included the 1,000 psia reference, the 3,000 psia system, and the 7,000 psia storage system. There are 4 options for high pressure gaseous resupply/storage (Options 1A-1D), 6 options for the cryo-supercritical resupply/storage configuration (Options 2A-2F), 1 option for subcritical liquid resupply/storage (Option 3), and 8 options for the dedicated high pressure gas configuration (Options 4A-4H). Of the 57 cases assessed, it was determined that the 3,000 psia storage subsystem option was the most cost effective for all INS options. The 5,000 psia minimum cost option was not evaluated with the overall systems and otherwise would constitute the lowest cost system. The storage subsystem cost results were explained in detail in the INS Contingency Storage Subsystem Tank Study, Section 6.5.7.

The bottom line cost figures resulting from the cost model trade study suggest that a fully integrated system with a cryogenic-supercritical resupply/storage subsystem is the most attractive option from a life cycle cost standpoint. This most cost effective option (Option 2D) uses a 600 psia cryogenic-supercritical supply subsystem for resupply/storage of the nitrogen required by users. The percent cost savings for the life cycle is about 14% over that of the most cost effective high pressure gaseous option (Reference Configuration, Option 1B). Although the subcritical liquid configuration results in approximately the same life cycle cost as this cryo-supercritical option, the technology for storage, maintenance and acquisition of liquid nitrogen in a low-g environment is still in the stages of development and poses considerable technological risk for design, development, and implementation at IOC. For adequate relative comparison with other nitrogen system options, a realistic complexity factor would have to be placed on the subcritical liquid tanks in the cost model, however a representative figure can not be accurately substantiated. Therefore, the same complexity factor was applied to both the cryo-supercritical and subcritical liquid tanks. The actual cost of a subcritical liquid system should probably be greater than that suggested by the cost model. The IOC cost of high pressure gas systems (Options 1A-1D) was considerably less than the cryogenic options, however this cost was more than offset by the fact that high pressure gas vessels are larger and heavier, resulting in higher launch and thus operating costs of such a system. Due to the low hardware commonality of the dedicated INS options (Options 4A-4H), life cycle costs exceed the Reference Configuration (1B) by up to 23% and the overall cost optimum cryogenic-supercritical option (Option 2D) by up to 43%.

The Life Cycle Cost analysis results are summarized in a series of tables and figures. Table 6.5-8 summarizes the overall life cycle cost figures for the candidate INS options with the 1,000, 3,000, and 7,000 psia storage subsystems. The 3,000 psia storage subsystem was priced with all options and the 1,000 and 7,000 psia options were assessed with the lowest cost INS option for each configuration (Options 1B, 2D, 3, 4C, and 4G). The options are indicated as the configuration (option) number itself, the configuration number with an "(a)" suffix, and the configuration number with a "(b)" suffix for the 1,000, 3,000, and 7,000 psia storage subsystem options, respectively. Table 6.5-9 lists the percent differences in LCC of the INS options from the Reference Configuration (1B) with the 3,000 psia storage subsystem. Also, Figure 6.5-9 illustrates the costs in Table 6.5-8, showing the IOC, operating and total LCC of each of the "(a)" configurations using a 3,000 psia storage subsystem. Figure 6.5-10 illustrates the cost difference of the options in terms of percent variation (Table 6.5-9) from the Reference Configuration (1B). Figure 6.5-11 shows the costs of the lowest cost option for each configuration so that a direct comparison can be made between the optimally cost effective options incorporating each supply subsystem concept. Similarly, Figure 6.5-12 shows how the minimum cost options for each configuration vary from the Reference. Again, the cost optimum options are 1B, 2D, 3, 4C, and 4G.

Table 6.5-8 Life Cycle Costs of Candidate Configurations (All Figures in $M)

Option #	IOC*	Life Cycle Cost - $M Operating**	Total Cost***
1A (a)	50.80M	349.3M	400.1M
1B	86.16	328.4	414.5
1B (a) Refer.	**55.62**	**318.4**	**374.0**
1B (b)	57.53	320.3	377.9
1C (a)	52.17	388.1	440.2
1D (a)	57.06	369.4	426.5
2A (a)	63.72	266.0	329.7
2B (a)	63.67	257.1	320.8
2C (a)	63.71	265.3	329.0
2D	93.63	266.3	359.9
2D (a)	**63.66**	**256.8**	**320.5**
2D (b)	64.98	258.3	323.2
2E (a)	63.79	269.9	333.7
2F (a)	63.76	261.6	325.4
3	90.16	267.5	357.6
3 (a)	**60.20**	**258.0**	**318.2**
3 (b)	61.51	259.4	320.9
4A (a)	63.00	358.8	421.8
4B (a)	64.60	391.5	456.1
4C	98.39	343.7	442.1
4C (a)	**67.85**	**333.7**	**401.5**
4C (b)	69.76	335.6	405.4
4D (a)	69.51	376.2	445.7
4E (a)	62.75	362.8	425.5
4F (a)	64.36	394.8	459.2
4G	98.15	347.7	445.8
4G (a)	**67.60**	**337.7**	**405.3**
4G (b)	69.51	339.6	409.2
4H (a)	69.27	379.5	448.8

* includes component, wrap-around, launch, initial propellant, and assembly costs
** includes propellant resupply, spare parts, maintenance, and deorbit costs
*** comprised of IOC and operating costs

Note : options in boldface type are the minimum cost options for each configuration

Table 6.5-9 Percent Difference in LCC from Reference Configuration (Configuration 1B(a))

Option #	Difference in LCC from Reference - %		
	IOC	Operating	Total Cost
1A (a)	-8.67	9.72	6.98
1B (a) Refer.	**0**	**0**	**0**
1C (a)	-6.20	21.9	17.7
1D (a)	2.59	16.0	14.0
2A (a)	14.6	-16.4	-11.8
2B (a)	14.5	-19.2	-14.2
2C (a)	14.5	-16.7	-12.0
2D (a)	**14.4**	**-19.3**	**-14.3**
2E (a)	14.7	-15.2	-10.8
2F (a)	14.6	-17.8	-13.0
3 (a)	**8.23**	**-19.0**	**-14.9**
4A (a)	13.3	12.7	12.8
4B (a)	16.1	23.0	22.0
4C (a)	**22.0**	**4.81**	**7.36**
4D (a)	25.0	18.2	19.2
4E (a)	12.8	13.9	13.8
4F (a)	15.7	24.0	22.8
4G (a)	**21.5**	**6.06**	**8.37**
4H (a)	24.5	19.2	20.0

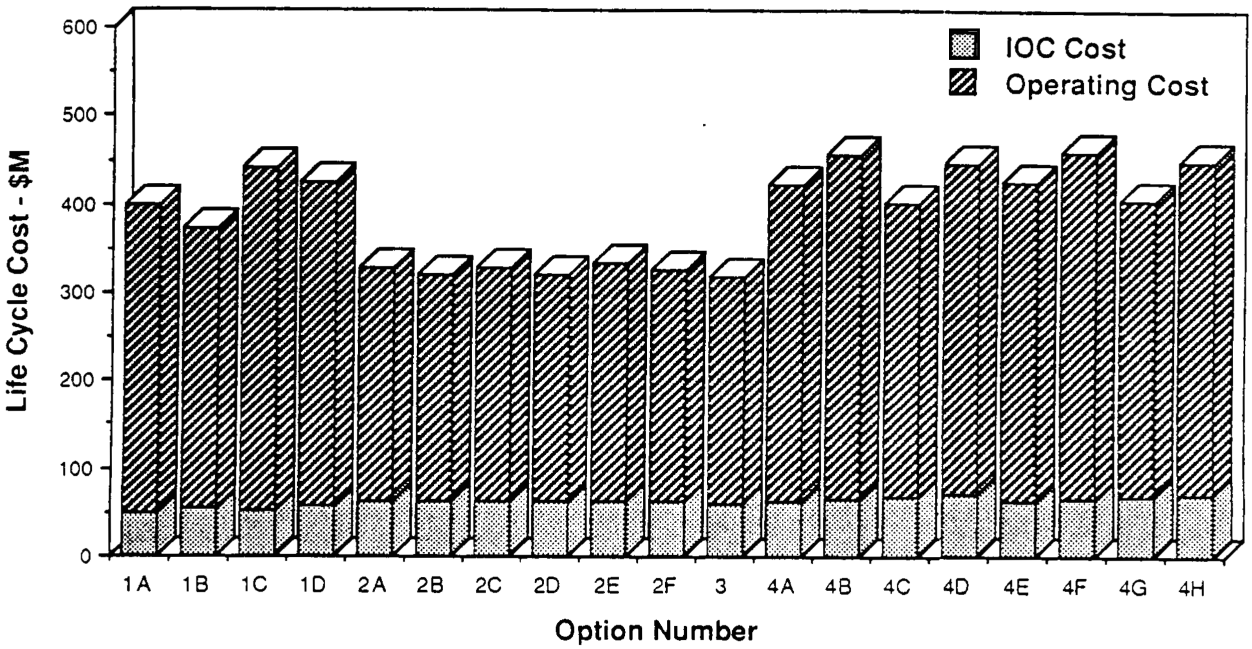

Figure 6.5-9 Life Cycle Costs of Candidate INS Configurations

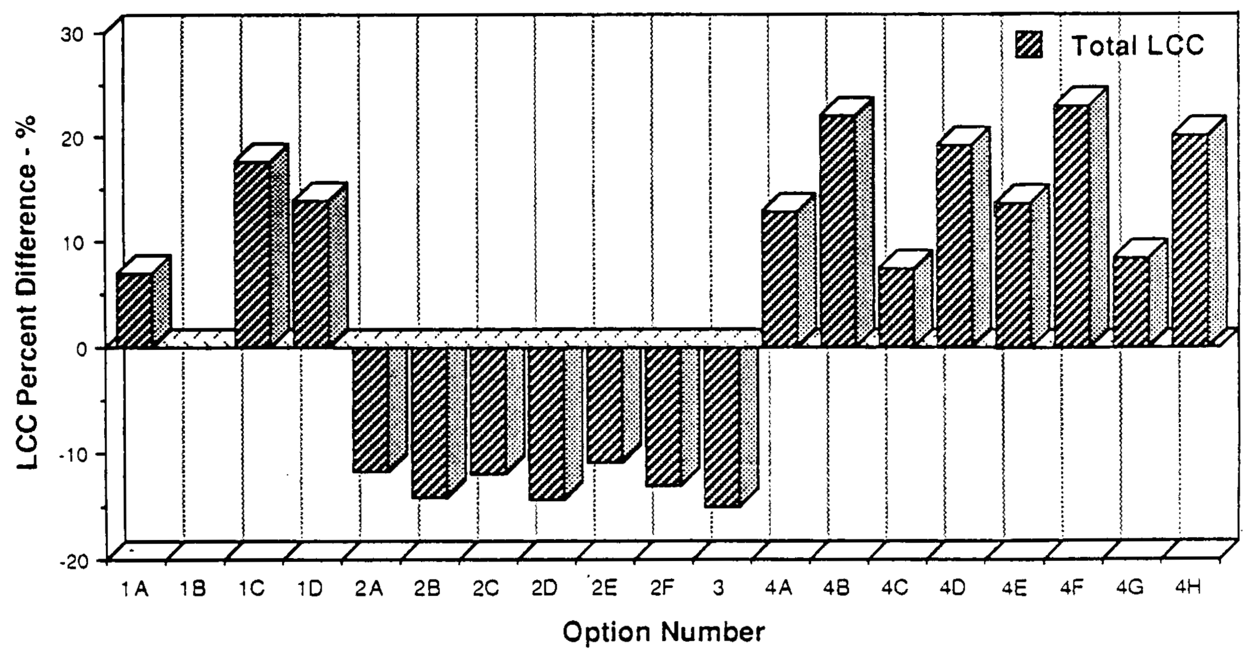

Figure 6.5-10 Percent Difference in LCC from Reference Configuration (1B)

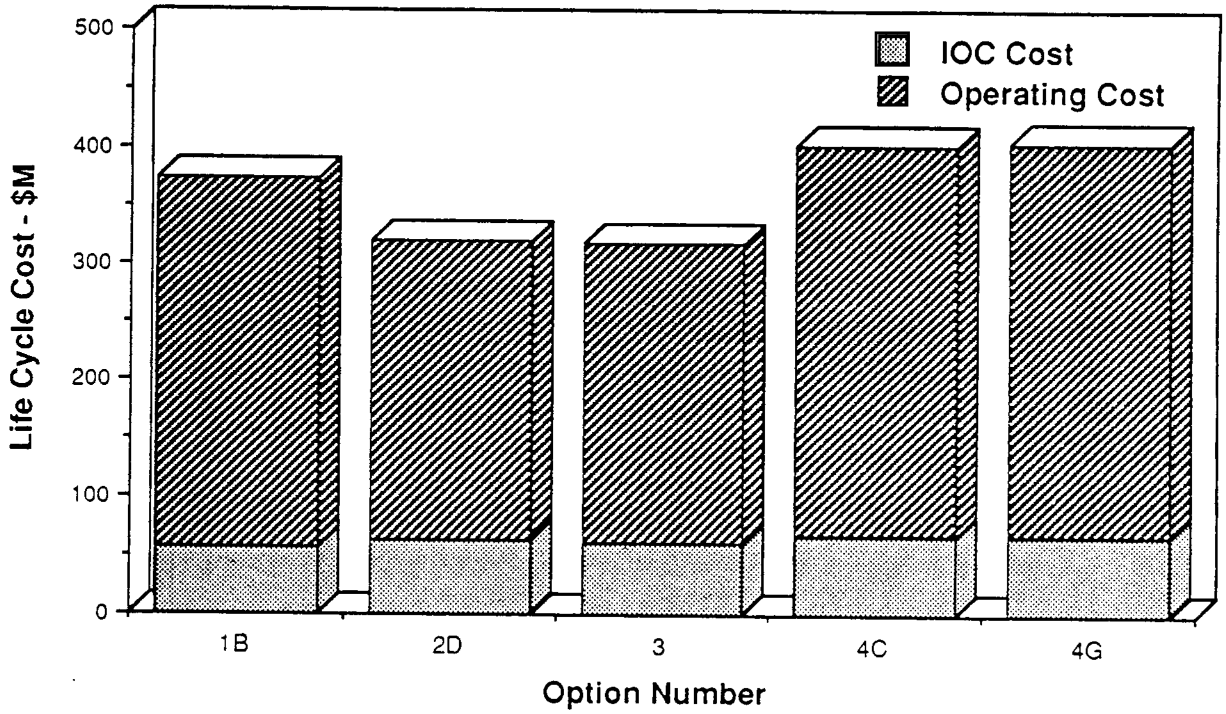

Figure 6.5-11 Life Cycle Costs of Minimum Cost Options

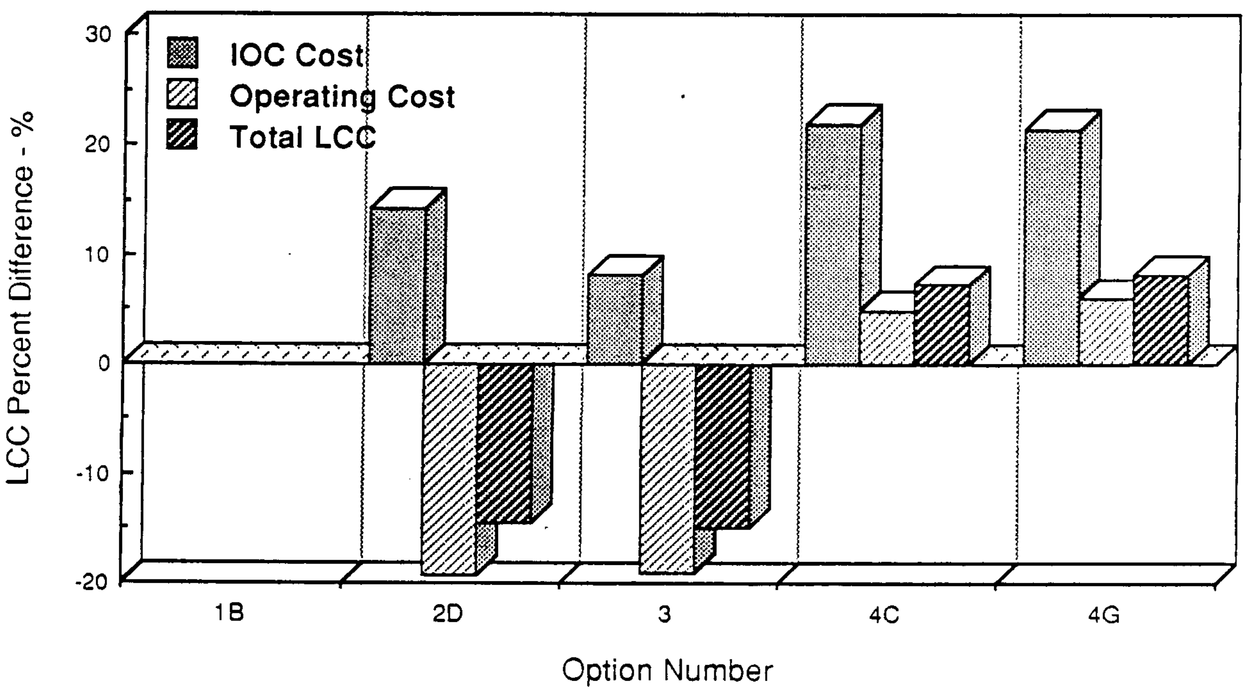

Figure 6.5-12 Percent Difference in LCC from Reference (Minimum Cost Options)

One of the areas of concern that arises in the development and evaluation of the INS options was whether or not the cost of procuring compressors for nitrogen delivery would be more cost effective than the costs inherent with otherwise deorbiting excess nitrogen. The implementation and use of compressors requires high initial development, qualification, and procurement costs, but substantially improves the nitrogen tank expulsion efficiency for a blowdown system. The required tank size, weight ,and the amount of nitrogen that would have to be deorbited is reduced due to increased pressure vessel efficiency. In Figure 6.5-9, IOC costs are slightly higher for the high pressure gas options with gaseous nitrogen compressors (Options 1B and 1D) as opposed to those without compressors (Options 1A and 1C), but the life cycle operating costs are significantly reduced, resulting in lower LCC. A similar trend is noticed with the partially integrated systems (Configuration 4, dedicated systems) where configuration Options 4C, 4D, 4G, and 4H use compressors for delivery of nitrogen to users. The IOC costs for the cryo-supercritical and subcritical liquid nitrogen options do not change since compressors are used in all cases; only the operating costs change. It can be seen in the figure that the options using compressors for nitrogen delivery (Options 2B, 2D, 2F, and 3) also result in lower operating costs due to the fact that tank systems are smaller and weigh less. The operating costs are reduced since less nitrogen and tank mass is launched and deorbited during shuttle resupply flights.

The life cycle cost may be reduced due to the possibility of recycling pure nitrogen already used by some of the interfaces. The nitrogen used by the IWS and IWFS interfaces for water and waste water pressurization in sealed bladder tanks may essentially be considered pure and recycled back into the INS distribution system. This nitrogen will have to be compressed back into the system, adapting well to systems that already use compressors for nitrogen management. Although the quantity of nitrogen that is still pure following use is small, recycling may reduce tankage sizes and launch quantities of nitrogen such that considerable cost savings may be realized over a life cycle.

Thought has been given to a cost effective methodology by which the storage subsystem tanks may be resupplied following use of emergency or contingency nitrogen. Cost savings could be realized if a lesser number of higher pressure vessels for resupply could accomplish the same transfer task as a larger number of lower pressure vessels. It may be feasible and cost effective to bring up high pressure gaseous nitrogen vessels strictly for the purposes of more efficient blowdown transfer resupply, especially where either high pressure gas vessels are not used for resupply (as with cryo-supercritical or subcritical supplies) or where compressors are not used for delivery or transfer. If compressors are already utilized for delivery of nitrogen to users, then the same compressors may be used for transfer as well. A higher pressure supply for blowdown transfer is not necessary when transfer repressurization is accomplished with compressors.

6.5.9 Scarring Requirements for Post-IOC (OMV, MMU, Vehicles, Platforms, etc.)

Scarring is required in the INS to accomodate Space Station EVA systems such as the OMV, MMU, EEU, free-fliers, platforms, and servicing facilities for post-IOC and during the Full Operational Capability (FOC). Currently, nitrogen requirements for these systems have been defined inadequately, in terms of resupply quantities, resupply frequency, and the types and numbers of spacecraft that will eventually need nitrogen during FOC. Fluid interfaces for these systems need better definition, which may be outlined from evaluation of spacecraft duty cycles and their proximity to the station. The post-IOC requirements call for gaseous N_2 with no mention of a need for liquid N_2, even though this need is suspected. The scarring developed in the INS for post-IOC interfacing will accomodate any integration of these vehicles and spacecraft systems into the overall gaseous nitrogen system. Over the course of post-IOC Space Station architecture development and implementation, it may be more justifiable to dedicate one or more GN_2 systems to the EVA spacecraft systems, especially if the roles and responsibilities of these systems are very different. The nitrogen requirements of many of the EVA systems and their potential for interfacing with the gaseous INS is presented below[10].

The gaseous nitrogen requirements for numerous Space Station support systems at post-IOC and their potential for integration into the overall gaseous INS was investigated by examining the fluid subsystems that require the nitrogen.

The independent spacecraft and on-orbit maintenance systems such as the OMV, MMU, EEU, free-fliers, platforms, etc. all require GN_2 for one or more purposes. The OMV uses a small amount of GN_2 for pressurization of its primary N_2H_4 RCS system and a large amount of GN_2 for the secondary GN_2 cold gas RCS system. Transfer and replenishment of N_2 to these systems is accomplished from the servicing facility on-orbit, or by interfacing an INS disconnect port at the scarred locations. The MMU's primary propulsion system uses GN_2 for its thrusters, which is recharged at a pressure between 250 and 3,000 psia at one of two of its quick disconnect interfaces with the INS system or with a servicing facility. Similarly, the free fliers and spacecraft platforms require GN_2 for propulsion and utility purposes which is also resupplied by the servicing facility on-orbit or at an INS interface at the station. The on-orbit systems that operate outside of the vacinity of the station will probably be serviced on-orbit by the servicing facility as opposed to those in the near vacinity of the station that would more than likely interface the INS.

6.6 CONCLUSIONS AND RECOMMENDATIONS

Numerous candidate INS configurations comprising various levels of integration were developed over the course of this program. These candidates were developed to assess commonality and integration concerns involved with the selection of a nitrogen system for incorporation into the overall fluid management system for the Space Station. The INS configurations studied were developed by combining a series of technologically viable supply, storage, and distribution subsystem concepts for resupply, storage, transfer, conditioning, control and monitoring, and distribution of nitrogen. The configurations included three different resupply/storage methods and two levels of integration within the Space Station. For each configuration, numerous options were devised that were either operationally of configurationally different, but supplied gaseous nitrogen to the same users throughout the Space Station. Analyses based on integration criteria and cost were performed to assess the credibility of each system option. Recommendations are made regarding the most feasible and cost effective system(s) for implementation into the Space Station fluid management system.

The levels of integration included full and partial (dedicated) integration of the gaseous systems and dedication of an independent liquid nitrogen system to USL experiment users. Integration is a very practical alternative for gaseous nitrogen users because the commonality advantage is enhanced by integrating the large number of users into a single fully integrated system. The types and numbers of components can be reduced as a higher level of integration is achieved. For all practical purposes, the liquid nitrogen system was evaluated as an independent system since it is difficult to see any merit in integrating the liquid and gaseous nitrogen users into a single totally integrated nitrogen system at this time. As currently defined, there are only a small number of LN_2 users confined to the USL module and they are in close proximity to one another. The simplest approach to supplying liquid nitrogen is to do so by resupplying liquid in dewars that are easily changed out of the USL and dedicated to the module experiments as a whole or to individual experiments. The complexity and cost involved with a totally integrated system that supplies both liquid and gaseous nitrogen from a common supply would be exhorbitant. Therefore, fully integrated gaseous N_2 and dedicated LN_2 systems are recommended as the nitrogen systems at IOC that are capable of satisfying all user demands and that optimize the commonality and cost factors.

The subcritical liquid nitrogen supply subsystem proved to be the most cost effective and required the least volume logistically for resupply. As the nitrogen resupply requirements increase, this approach will provide the greatest flexibility and integration potential with the USL and international liquid resupply systems. However, it is questionable whether or not the required technology to design and develop a liquid nitrogen system will be available in time for implementation on the Space Station at IOC. On-orbit experimentation will be required to demonstrate liquid nitrogen storage and transfer capabilities prior to design verification.

An alternative approach would be to provide a cryogenic-supercritical nitrogen supply/storage system with combination delivery/transfer compressors in the event that subcritical liquid technology is not available. The recommended operating pressure of this system is 600 psia, a level above the critical pressure of nitrogen, but not so high that it causes safety concerns or inefficient conditioning of N_2. The cryo-supercritical approach reduces the total life cycle costs of the INS by up to 14% over that of the Reference high pressure gas resupply concept, and is comparable to the cost of a subcritical liquid system. The IOC cost of the cryo-supercritical system is 14% more, but the operating costs, which are the major contributor to LCC, are about 19% less than the Reference Configuration. Compressors are used to improve the expulsion efficiency of supply subsystem pressure vessels and to effectively reduce the life cycle launch costs since less nitrogen has to be resupplied and deorbited. Compressors are also used to transfer N_2 for resupply of the contingency storage subsystem pressure vessels. This system reduces the logistic resupply requirements and provides flexibility for growth, similar to the subcritical liquid concept.

The high pressure contingency storage subsystem at 5,000 psia was the optimum option on the basis of cost; however, other options ranging in pressure from 2,000 to 8,000 psia were very close in cost and relatively similar in size. A system in this range is recommended for application to the gaseous nitrogen system selected for the Space Station. The actual operating pressure will be determined by the compressors' capability to transfer nitrogen to the storage subsystem. Below 2,000 psia, the system sizes, weights, and costs became very excessive. A high pressure contingency storage subsystem was chosen over options such as cryogenic storage due to its simplicity in design, and efficiency for potential long-term storage. The need for long-term nitrogen conditioning with gaseous nitrogen storage is nonexistent. A high pressure storage system will deliver nitrogen by blowdown at more adequate flowrates than a lower pressure system, and do so on demand without the need for intermediate steps such as gas compression. Furthermore, the resupply process is simplified following use of emergency or contingency nitrogen since gas is readily transferred to the storage subsystem pressure vessels from the supply subsystem. A high pressure cryogenic supply is impractical and requires much fluid conditioning at high power consumption levels. Cryogenic storage vessels may not be efficiently resupplied on-board and instead will have to be replaced and traded out, requiring unnecessary and costly resupply activity.

6.7 REFERENCES

1) Fluid Systems Configuration Databook, EP 2.1: MCR-87-578, pages 65 and 76, dated 9 July 1987.

2) Space Station Program Definition and Requirements, Section 3: Systems Requirements, SS-SRD-0001, Issue: Revision A, Section 2.1.14.1, January 12, 1987.

3) Data Released 12 February 1987, Technical Interchange Panel Information, Eric Streams, McDonnell-Douglas Astronautics Company.

4) Space Station Definition and Preliminary Design, WP-01, End Item Databook, Book 3, SSP-MMC-00031, Martin Marietta, October 31, 1986.

5) Architectural Control Document, Fluid Management System, Section 1: Integrated Nitrogen System, NASA JSC 30264, Space Station Program Office, December 1, 1986.

6) G.M. Holmstead, "ECLSS System Mass Balance Cases", Martin Marietta Memorandum, dated 26 March 1987.

7) Space Station Program Fluid Inventory Databook, EP 2.2: MCR-87-579, dated 9 July 1987.

8) Fluids Interchange Panel Information Presented by Sam Dominick Representing Martin Marietta, dated 18 March 1986.

9) Telephone Conversations with Sam Dominick on 12 November 1987, 06 January 1988, and 22 January 1988, Martin Marietta Space Systems Company.

10) Space Station Architecture Propellant Systems Databook, EP 1.1: MCR-87-516, Martin Marietta Denver Aerospace, dated 2 April 1987.

7.0 INTEGRATED WASTE FLUID SYSTEM

7.1 OVERVIEW OF THE INTEGRATED WASTE FLUID SYSTEM ASSESSMENT

The overall functions of the Integrated Waste Fluid System (IWFS) are to collect and store waste gases and waste water discarded by the station elements for use in resistojet venting. This is a very complex system because it requires the transfer, storage, and conditioning of the waste effluents and the control and monitoring of each of these processes to ensure a safe envronment for crew members and to ensure that contamination restrictions during on-orbit venting have been met.

The IWFS reference configuration used during this assessment is schematically presented in Figure 7.1-1[1]. This design concept consists of a central collection and storage system and a vacuum vent system. Waste effluents are initially transferred from the station elements to the central collection and storage waste system through either a reducing line or oxidizer line, for waste gases, or a waste water line used exclusively for excess water. The transfer process for the gaseous systems occurs until the line pressure in the specific element reaches 0.25 torr at which time the central waste system is closed and the remaining effluents are evacuated to space through the vacuum vent line. This design concept also provides the collection of waste water from the experiments,

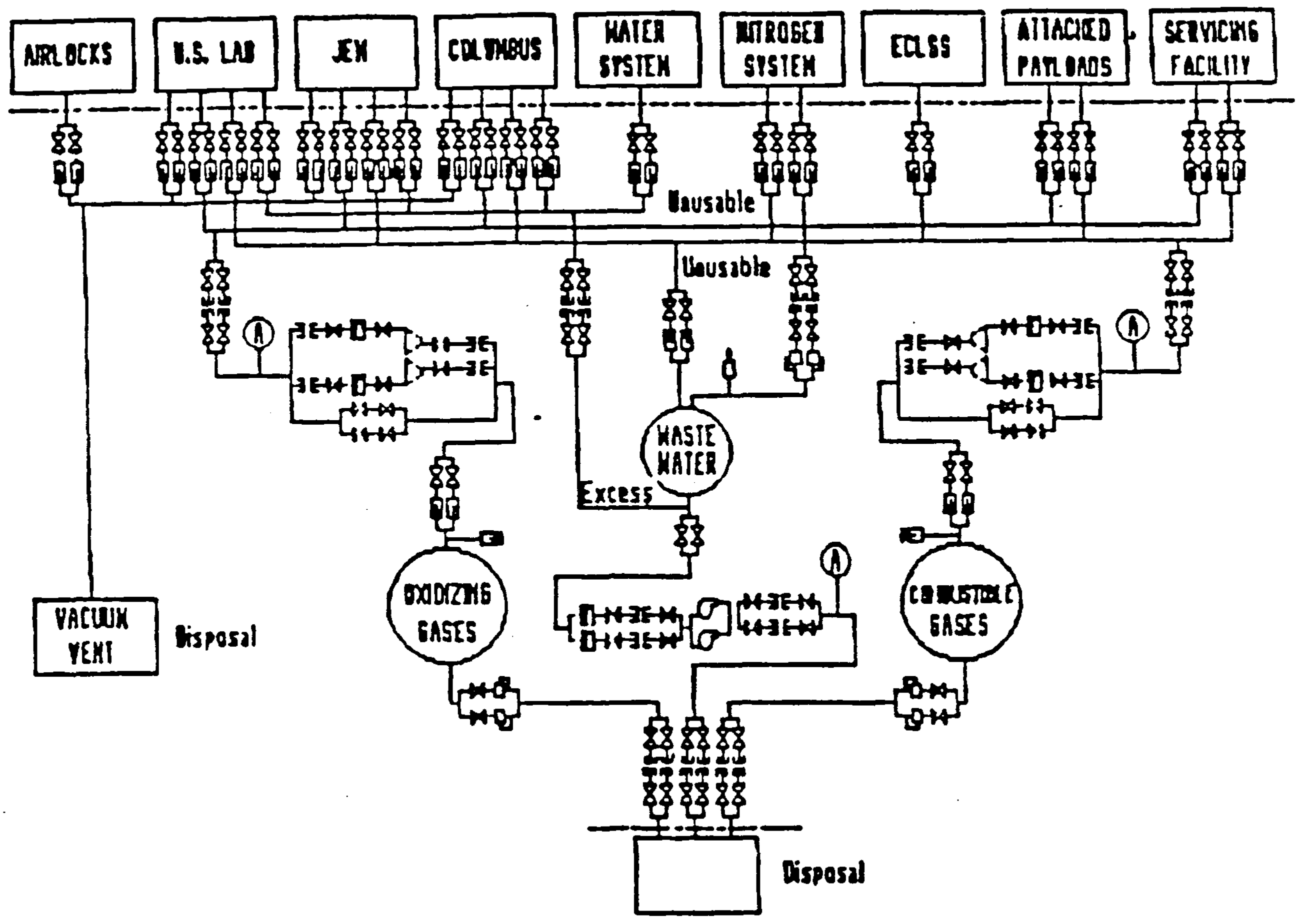

Figure 7.1-1 Integrated Waste Fluid System Reference Configuration

the Environmental Control and Life Support System, and the integrated water system. To meet long duration hold times imposed by the external environment criteria, the storage facility must accomodate a 15 day hold time before propulsively venting the effluents through resistojets. A detailed discussion of the IWFS reference configuration is provided in EP 2.1, the "Fluid Systems Configuration Databook."

As a means of assessing the IWFS reference configuration and developing alternate design configurations, an evalutation of the current fluid inventory was gererated and resistojet venting restrictions were established. In conjunction, a thorough investigation of the contributing systems was performed to establish methods of collecting and conditioning waste effluents, and to identify methods for recycling waste effluents rather than disposing of them.

7.1.1 Integrated Waste Fluid System Inventory and Space Station Element Contributors

Space Station elements contributing to the Integrated Waste Fluid System include the four core Modules (United States Laboratory, Habitation, Japanese Experiment, and Columbus), the integrated nitrogen and water systems, Attached Payloads, environmental control and life support systems, and the fluids servicing facility. A careful inspection of each of the waste fluid contributors led to a revised functional schematic which assisted in assessing the current configuration and developing a recommended approach. The functional schematic is presented in Figure 7.1-2.

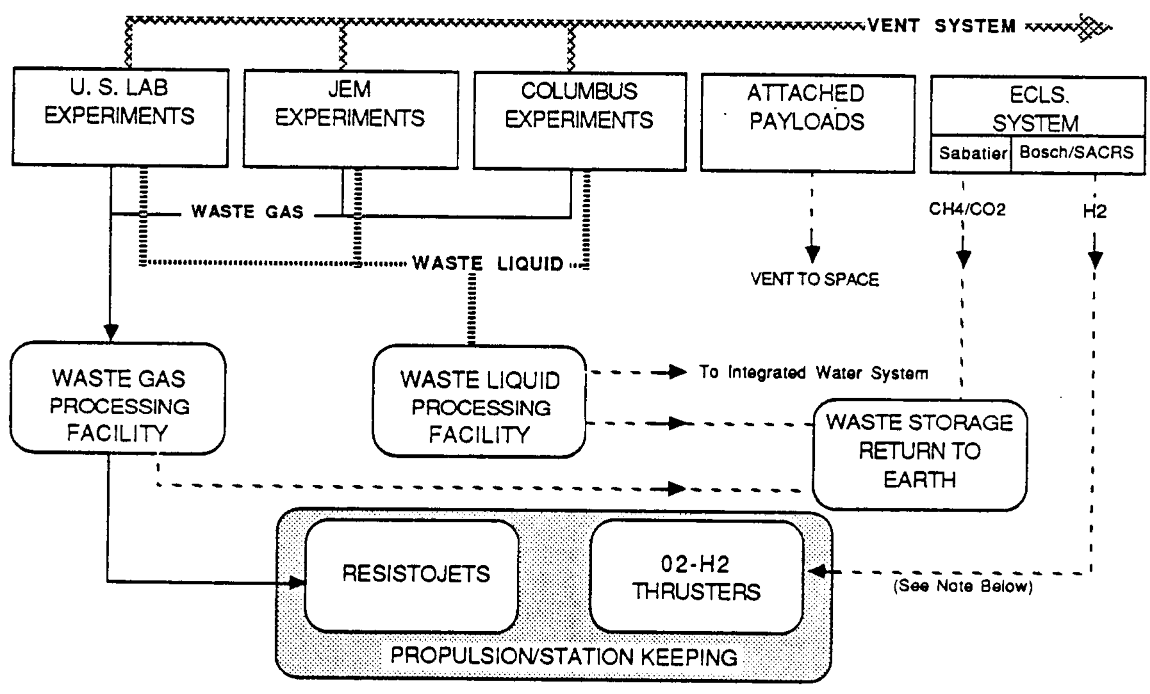

Figure 7.1-2 Integrated Waste Fluid System Functional Schematic

7.1.1.1 Experiment Fluids - Waste fluids contributed by the experiment modules were examined by assessing the Martin Marietta and Boeing DR-O2 concepts for the Process Waste Handling System (PWHS) in the USL Module[2,3] and by establishing fluid inventory data from the

"Microgravity and Materials Processing Facility (MMPF) Study Data Release"[4] and Fluids Technical Interchange Panel information[5,6]. The process waste handling systems are discussed in detail in section 7.2 along with the an assessment of the experimental effluents transferred to the IWFS.

7.1.1.2 Waste Water - As defined in EP 2.1, the "Space Station Program Fluid Systems Configuration Databook", no experiments are presently transferring waste water to the IWFS. As a result, the only excess water defined is the potable water stored in the integrated water system. A water balance sensitivity analysis discussed in section 6.0 of this report indicated that in most instances additional water will be required to meet the high water demands of the crew, the experiments and the propulsion system, and that only a slight amount of water at any given time may be in excess. However, if there is an excess of potable water, the options are to transfer the water to the oxygen/hydrogen propulsion system or to transfer less water to the Integrated Water System from the potable water storage in the Space Shuttle fuel cells. Water can be used by the propulsion system either as steam through resistojets or as electrolysis produced oxygen and hydrogen burned in conventional thrusters. The specific impulse of the resistojets using steam is 188 seconds as compared to a specific impulse of 380 seconds using the oxygen/hydrogen thrusters. Therefore, pound for pound, water used in the oxygen/hydrogen thrusters would provide better performance than it would in resistojets. As a result, the established reference configuration elimated the use of waste water in the resistojets and the waste nitrogen used to perform the water transfer.

7.1.1.3 Environmental Control and Life Support System (ECLSS) - The type of waste effluents contributed to the IWFS from the ECLSS depend on the carbon reduction process used for life support functions. Gaseous hydrogen is the primary effluent from the Bosch carbon dioxide reduction process. This hydrogen contains traces of water vapor, however it can be desiccated and used in the oxygen/hydrogen thrusters. An additional amount of hydrogen reduces the mixture ratio and increases the thruster specific impulse. This results in a reduction of water required for propulsion and a reduction in overall life cycle costs. A cost analysis showed a greater cost advantage of using the hydrogen in the oxygen/hydrogen thrusters as compared to using it in the resistojets.

The primary effluent from the Sabatier CO_2 reduction process is a mixture of carbon dioxide and methane. As discussed in section 7.6 of this report, venting this mixture at high temperatures may result in carbon deposition in the resistojets. To prevent carbon deposition during venting, the resistojets may be required to operate at inefficiently low temperatures. An alternate method for preventing carbon deposition is to increase the amount of CO_2 and add steam to the mixture. Extensive testing will be required to verify the effectiveness of each of these methods.

A life cycle cost comparison was performed comparing the Bosch and Sabatier processes assuming that the Bosch hydrogen could be used in the oxygen/hydrogen thrusters, and the Sabatier carbon dioxide/methane mixture could be vented through resistojets at a specific impulse of 140 seconds. In all cases, the Bosch CO_2 reduction process proved to be the least expensive. The cost benefits were a direct result of a reduction in hardware and water resupply requirements, in addition to an overall improvement in the Space Station reboost performance gained by using hydrogen in the oxygen/hydrogen thrusters as compared to using the carbon dioxide/methane mixture in the resistojets. Another factor considered was that an IWFS integrated with a Bosch ECLSS system would require less developmental testing and would conceivably be less risky. Therefore, the recommended approach for integrating the ECLSS with the IWFS would be to incorporate the Bosch CO_2 reduction process or an advanced Sabatier process that would remove the hydrocarbons from the waste effluents prior to transfer to the IWFS.

7.1.1.4 Servicing Facility - No fluids were identified during the performance of this study.

7.1.1.5 Attached Payloads - Potential fluids available from the Attached Payloads were established from the NASA Lewis Study[7] and through telephone conversations with designated Attached Payload consultants [8-12]. Preliminary information indicated a substantial amount of carbon dioxide, nitrogen, helium, argon, and hydrogen available for resistojet venting. However, further discussions with the principal investigators of each of the identified experiments revealed that these fluids were not available for resistojet venting. In addition, discussions with the NASA Goddard personnel indicated that future Attached Payloads would also not be available for resistojet venting because of the need to perform vacuum venting to maintain the necessary pressures for instrument cooling and highly sentive operational performance. Therefore Attached Payload waste effluents were not included in the reference configuration. However, if effluents are identified in the future, they may be integrated into the recommended IWFS conceptual design with minor modifications.

7.2 PROCESS WASTE HANDLING SYSTEM DEFINED IN THE MARTIN MARIETTA AND BOEING DR-02 DATABOOKS

The Martin Marietta Phase B DR-02 baseline concept for the process waste handling systems is shown in Figure 7.2-1. The various facilities and experiments have up to four interfaces with the waste fluid system including the vacuum vent, combustible gases, oxidizing gases, and waste water. These wastes are transferred and processed separately. A detailed discussion of the system is presented in Section 7.2.1.

The Boeing Phase B DR-02 concept for the process waste handling system is shown in Figure 7.2-2. Two-phase flow, containing a mixture of various gases and liquid wastes, is transferred from the experiments to the waste system where gases and liquids are separated for processing. A detailed discussion of the system is presented in Section 7.2.1.

7.2.1 Comparison of Martin Marietta and Boeing Process Waste Handling Concepts

General - The concepts for waste fluid management presented in both the Boeing and Martin Marietta Space Station Phase B DR-02 documents are fairly conceptual in design with little detailed information which can be objectively evaluated. The overall design approaches and philosophies supporting each concept are presented in Table 7.2-1.

Technology Needs - The technology needs for the Boeing and Martin Marietta concepts are very similar. The key areas which need development are gas/liquid separators and instrumentation required for monitoring waste gases. They are considered key development areas since they are required for nearly all approaches to handling waste fluids. Vacuum pumps may also need considerable development if, as in the Boeing concept, they are required to maintain 2×10^{-5} psia (10^{-3} torr) and handle two or three phase flow (gases, liquids, and frozen liquids and particles). Filters or particulate traps which can stand up to the harsh environments are also necessary for all concepts, but their development is less technically challenging. However, there will be extensive materials compatibility issues to be worked which will impact all piping and fluid handling components. If waste gases are to be piped external to the module and/or used in resistojets, dehumidification of the gases may be a potential issue since condensing liquids can restrict lines.

Safety - The key safety issue is the potential incompatibility of various wastes. Experiment effluents include a broad spectrum of fuels, oxidizers, and inert fluids, chemicals with varying pH ranges, and numerous chemicals considered inherently hazardous. At the onset, the prospect of combining incompatible substances seems both inevitable and intolerable as discussed in Section 7.4. However, the Martin Marietta concept of separating fuels and oxidizers at the source is acceptable if possible.

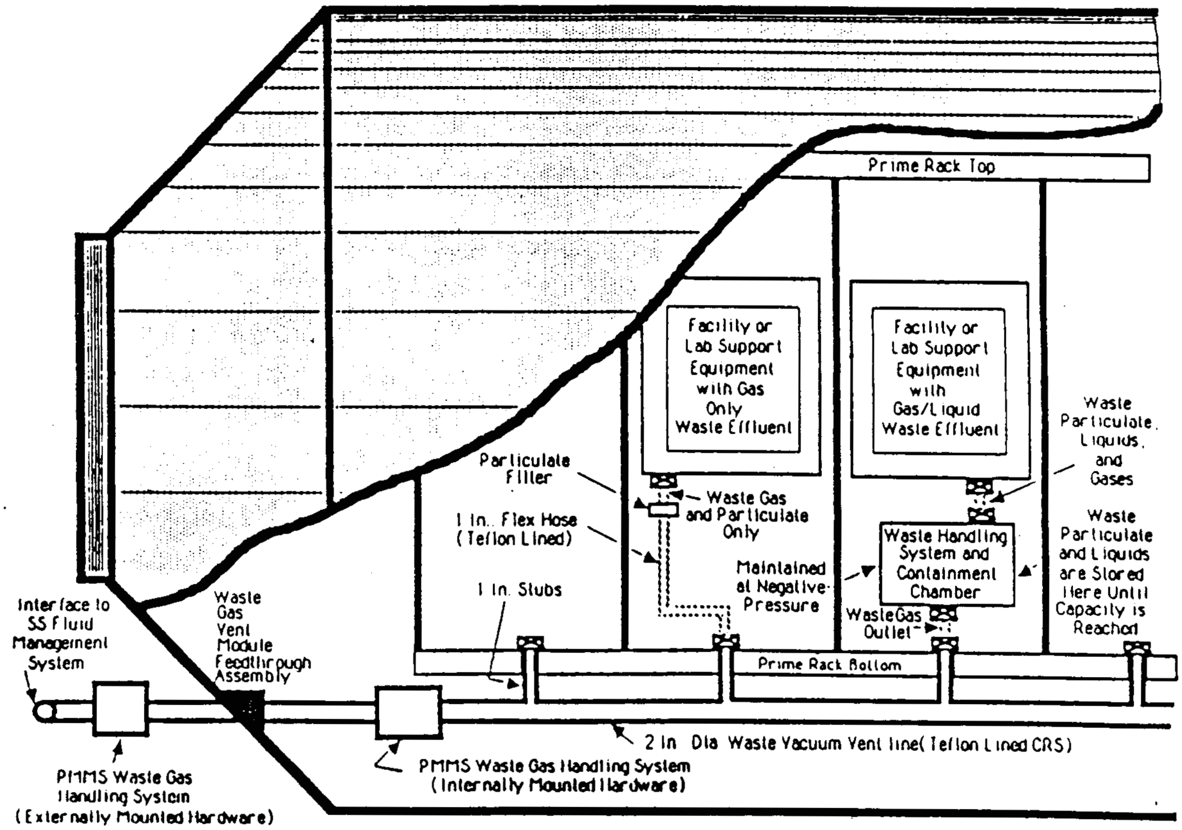

Figure 7.2-1 USL Process Waste Handling System - Martin Marietta Concept

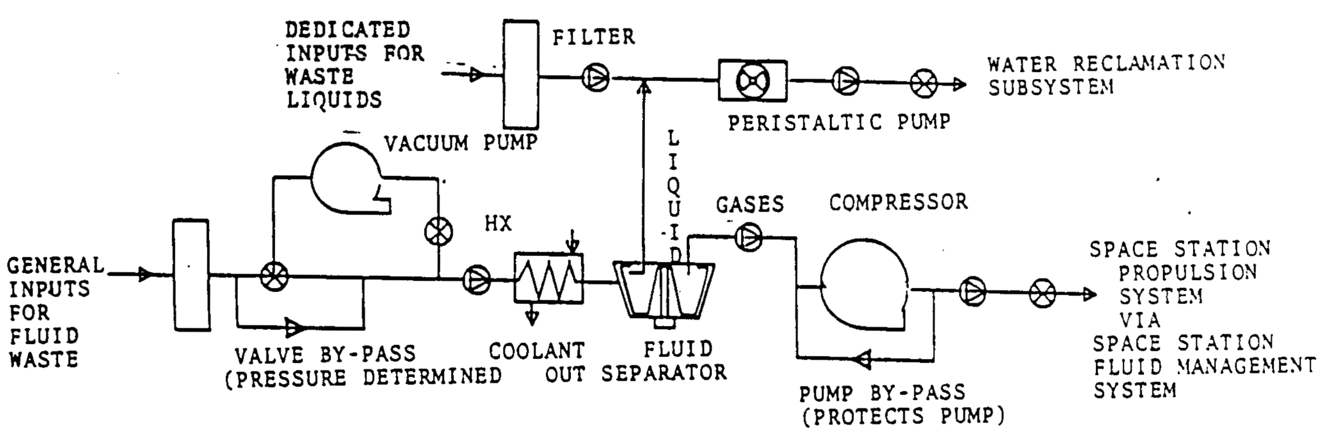

Figure 7.2-2 USL Process Waste Handling System - Boeing Concept

Table 7.2-1 Evaluation of Waste Fluid System Baseline Concepts

EVALUATION CRITERIA	BOEING BASELINE	MARTIN MARIETTA BASELINE
Technology Needs	- Phase Separators (L/G) - Particle Traps - Vacuum Pump ($10E^{-3}$ Torr, 2 Phase) - Piping/ Assoc Hardware - Monitoring Equipment - Waste gas Dehumidification	- Phase Separators (L/G) - Particle Filters - Fluid Line Coupling - Piping/ Fluid Handling Monitoring Equipment - Leak Detection - Cryo N2 Liquifaction - Waste Gas Dehumidification
Safety	- Fuels/Oxidizers Mixed - Hazardous Liquids Transferred to External Storage Tanks	- Fuels/Oxidizers Separated - Hazardous Liquids Contained in Dedicated Storage Tanks in Experiment Racks
Location Impacts	- Insufficient Information	- Insufficient Information
Maintenance - IVA vs EVA - Frequency - Safety	- Minimal IVA Planned - Anticipate High Unplanned Maintenance Due to Vacuum Pump Reqmts and Anticipated Life	- Higher IVA Planned to to Maximize Crew Safety - Anticipate High Unplanned Maintenance Due to Number of Components - EVA Required for Waste Tank Changeout
Materials Compatibility	- Potential Problems with both. Design Requires More Definition - Fuels/Oxidizers Combined - Unspecified Processing of Gases Prior to resistojet	- Fuels/Oxidizers Separated to to minimize Incompatibilities - Catalytic Combustion Process Used to Safe Waste Gases - Further Definition Required
Power Evaluation - Peak - Average	- Insufficient Design Data and Definitions	- Insufficient Design Data and Definition
Microgravity Impact	- Rotating Machinery in Experiment Boxes for Fluid Moving	- Rotating Machinery in Experiment Boxes for Fluid Moving/PhasSeparation
Industrial Approaches/ Applicability.	- Standard Piping Hardware Components - Some Standard Water Processing Technologies (Carbon Absorption, Reverse Osmosis). Applicability Uncertain Until Experiments are Defined and Performance Tests Completed.	- Standard Piping Hardware Components - Some Standard Water Processing Technologies (Absorption/Ion Exchange Media). Applicability Established by tests Performed by MDAC.

Table 7.2-1 Evaluation of Waste Fluid System Baseline Concepts (Continued)

EVALUATION CRITERIA	BOEING BASELINE	MARTIN MARIETTA BASELINE
Industrial Approaches/ Applicability	- Vacuum Vent Approach is Questionable	
Viability of Alternative Concepts	- Requires Further Design Definition	- Requires Further Design Definition
System Breadboard Recommendations	- Implement Use of Waste Gases in resistojet for Reboost	- Implement Separation of Phases in Experiment Racks; Retention of Hazardous Wastes at Rack Level.

The Martin Marietta philosophy on safety requires containing hazardous wastes at the rack level where they are produced or used. This minimizes the potential of leakage via rack connections and subsequent damage to the vehicle structure and equipment. However, it requires increased crew time for transporting the hazardous waste tanks from the racks to storage facilities in the logistics module, and it requires increased weight, and therefore cost, for return of these individual storage tanks to Earth.

The Boeing approach to handling hazardous fluid wastes is to transfer them via a piping system to storage tanks located external to the modules. This minimizes the potential for a major spill or leak from a storage tank, but increases the risk of leakage from connections in the piping. The crew does not handle the waste tanks except when changeout of the external tank is required. It is assumed that this changeout can be accomplished by extravehicular activity (EVA) or through the use of a robotic manipulator. Either option will require expenditure of crew time. The Boeing approach also mixes chemicals which are already labeled as hazardous with other hazardous chemicals. Very careful consideration of such a plan is mandatory before this philosophy is employed.

<u>Location Impacts</u> - The data provided in the DR-02 data documents are insufficient to define any location constraints for equipment or experiments.

<u>Maintenance</u> - Maintenance requirements for the Boeing and Martin Marietta baseline concepts reflect the basic design philosophies. The Boeing concept minimizes intravehicular activity (IVA) by transferring non-processable fluid wastes to an external tank via fluids interconnecting the experiment racks. Changeout of the waste liquid tank could be performed either through EVA or the use of a remote manipulator.

The Martin Marietta concept does not transfer the non-processable liquid wastes, but rather stores the wastes in the individual experiment racks. Consequently, increased IVA is required to replace the waste fluid tanks in each experiment requiring the waste fluid storage.

Both concepts will require excessive maintenance due to compressor/vacuum pump requirements and their associated short life. The Martin Marietta concept also requires a higher level of maintenance due to the higher number of components.

Material Compatibility - The Boeing concept has potential problems with both waste-to-waste and waste-to-system incompatibilities. The degree of these problems cannot be completely defined without further design definition. It appears that fuels and oxidizers are not separated prior to transfer and the processing of waste gases prior to resistojet is undefined.

The Martin Marietta baseline separates fuels from oxidizers to prevent potential hazardous reactions between wastes. Catalytic combustion of gases is performed prior to being transferred to the resistojets.

Both the Boeing and Martin Marietta concepts require further definition.

Power Requirements - The data provided in the DR-02 data documents are of insufficient detail to determine average and peak power requirements. The major power consumers will most likely be the vacuum pumps and the power requirements will be a function of the level of vacuum required.

Microgravity Impacts - Both the Boeing and Martin Marietta baselines have rotating machinery in the experiment boxes. It is anticipated that this will have an unacceptable impact on the microgravity environment for some of the experiments.

Industrial Approaches/Applicability - Both Boeing and Martin Marietta use standard piping hardware and components. Standard water processing technologies, such as charcoal adsorption and ion exchange are used in both concepts. The Boeing baseline also uses reverse osmosis for water processing. The applicability of this approach will remain uncertain until experiments are defined and some performance tests are completed. The Martin Marietta baseline uses a TIMES (Thermoelectric Integrated Membrane Evaporation Subsystem) water processor. Tests on both actual and ersatz experiment waste water have been performed to establish the feasibility of this concept.

Viability of Alternate Concepts - The viability of alternate concepts is difficult to ascertain at this time based on the degree of design definition. However, some philosophies and design features are discussed in Section 7.5.

System Breadboard Recommendations - The recommended breadboard system is described in Section 7.10.

7.3 ASSUMPTIONS, GROUNDRULES, AND DESIGN PHILOSOPHY FOR A RECOMMENDED APPROACH FOR THE PROCESS WASTE HANDLING SYSTEM AND THE INTEGRATED WASTE FLUID SYSTEM DESIGN

To design a waste fluid management system, it was necessary to assume a set of experiments that would be run in the US Laboratory and to assume that similar experiments would be concurrently taking place in the JEM and Columbus modules. The fourteen experiments considered for these experiments are shown in Table 7.3-1. Tables E-1 through E-14 in Appendix E show the facilities used during each experiment, the quantities of chemicals required, and the phase and hazards of these chemicals.

An inspection of the experiment fluids indicated that some of the chemicals were not compatible with the IWFS. However, some of these chemicals can be reacted to produce by-products which can be safely processed by the IWFS. Some suggestions for reactions of this type are provided in section 7.4 of this report. Chemicals that are found to be hazardous and incompatible with the IWFS, and cannot be reacted to produce nonhazardous by-products are assumed to be stored within the experiment for return to Earth for disposal.

Table 7.3-1 Baseline Experiments

Acoustic Containerless Processing
Continuous Flow Electrophoresis
Directional Solidification
Droplet Burning
Electroepitaxy Crystal Growth
Electromagnetic Levitation
Free Surface Phenomena
Membrane Production Facility
Monodisperse Latex Spheres
Protein Crystal Growth
Solidification of Immiscible Alloys
Solid Surface Burning
Solution Crystal Growth
Vapor Phase Crystal Growth

Experimenters are assumed to be responsible for verifying that waste effluents are compatible for transfer to the IWFS. This may mean that substitute effluents or waste storage within the experiment will be required. In addition, experimenters are assumed to provide temperature, pressure, and composition control before dumping their waste effluents.

The assumption that the experiments and their procedures preclude release of free liquids into the experiment facilities is also made. This requirement would probably come about naturally because of the necessity to use liquid acquisition systems to transfer fluids in low-gravity. An examination of the experiment configurations (as discussed in Section 7.5) indicates this assumption to be true with the exception of the fluids glovebox and cutting and polishing facilities. Recommended approaches are provided to sustain this requirement of handling only gaseous wastes or liquid wastes at any given time. Particulates should be controlled also, and are assumed to be removed from both the liquid and gas lines through filtration. Both systems will be filtered as a routine matter to protect downstream components.

The final groundrule is that venting operations will be scheduled to occur only during periods that will not impact experiment operations. More discussion of this point is included in Section 7.7.

7.4 ASSESSMENT OF HAZARDOUS CHEMICALS AND POTENTIALLY HAZARDOUS CONDITIONS IN THE US LABORATORY

Table 7.4-1 lists the most hazardous chemicals used in the 14 baseline experiments. Some of these chemicals can be explosive under the proper conditions, some react quickly or violently, while others are highly toxic. From the list of experiments considered in this study, these chemicals were determined the most hazardous and, accordingly, these are the chemicals that should be very carefully monitored. Substitutes are recommended where possible.

Experiment details available at this time, are insufficient to determine whether there are serious problems associated with the usage and isolation of the atmosphere in the module. For example, acetylene is toxic and explosive in air, but only about 1.2×10^{-6} lbm will be used each 90 days. This may be used as a reference material, but the quantity is so low that the only concerns are in the storage area and nothing has been specified to indicate how or where it will be stored. Alternately, the quantity of beryllium is unspecified, but hazards to humans are very likely if the smallest of particulates escapes from any part of the experimental apparatus into the astronauts' atmosphere. In this case, it is already known that the strictest of measures will have to be employed for the astronauts' safety (see also Section 7.11).

Table 7.4-1 USL Hazardous Fluids Assessment

EXPERIMENT	HAZARDOUS MATERIAL	PHASE	MASS VENTED (LBM)	COMMENTS
CONTINUOUS FLOW ELECTROPHORESIS	SODIUM AZIDE	L,G	0.0055	EXPLOSIVE; RECOMMEND USING GLUTERALDEHYDE INSTEAD
DIRECTIONAL SOLIDIFICATION	MERCURY	P,L,G	UNCERTAIN	DEATH WITHIN DAYS OF CHRONIC EXPOSURE; ABSORBED AS A LIQUID OR VAPOR
	CADMIUM	P,G	UNCERTAIN	CARCINOGEN; MAY CAUSE BRONCHOPNEUMONIA. HIGH VAPOR PRESSURE FOR A METAL
	BERYLLIUM	P	UNCERTAIN	CARCINOGEN; DEATH MAY RESULT FROM VERY SHORT EXPOSURE TO VERY LOW CONCENTRATIONS
DROPLET BURNING (GAS CHROMATOGRAPH FACILITY)	ACETYLENE	G	0.0000012	TOXIC AND EXPLOSIVE; NEED TO CONSIDER QUANTITY, STORAGE AND METHOD OF USE
ELECTROEPITAXY	ARSENIC	P	UNCERTAIN	CARCINOGEN; MOST FORMS ARE TOXIC
SOLIDIFICATION OF IMMISCIBLE ALLOYS	BERYLLIUM	P	UNCERTAIN	CARCINOGEN; DEATH MAY RESULT FROM VERY SHORT EXPOSURE TO VERY LOW CONCENTRATIONS
SOLID SURFACE BURNING (GAS CHROMATOGRAPH FACILITY)	POTASSIUM	S	UNCERTAIN	EXTREMELY REACTIVE; INFLAMES WITH WATER
	ACETYLENE	G	0.0000012	TOXIC AND EXPLOSIVE; NEED TO CONSIDER QUANTITY, STORAGE AND METHOD OF USE
	LITHIUM	S	UNCERTAIN	REACTS SLOWLY WITH WATER TO PRODUCE H2; HAZARD IN CONTAINED AREA; RECOMMEND COMBINING WITH WATER FOLLOWED BY DILUTE HCl TO MAKE INTO A SALT (LiCl) AND H2 BEFORE ENTERING WASTE FLUID SYSTEM
	MAGNESIUM	P,S	UNCERTAIN	REACTS READILY WITH DILUTE ACIDS TO PRODUCE H2; HAZARD IN CONTAINED AREA; RECOMMEND COMBINING WITH DILUTE HCl TO MAKE INTO A SALT (MgCl2) AND H2 BEFORE ENTERING INTO WASTE FLUID SYSTEM
SOLUTION CRYSTAL GROWTH	SODIUM CHLORATE	P,L	UNCERTAIN	STRONG OXIDIZER; AVOID CONTACT WITH ORGANICS
	HYDROGEN PEROXIDE	L,G	UNCERTAIN	MAY DECOMPOSE VIOLENTLY IF TRACES OF IMPURITIES ARE PRESENT
	HYDROFLUORIC ACID	L,G	UNCERTAIN	POISONOUS, MAY CAUSE TOTAL DESTRUCTION OF EYES.
	NITRIC ACID	L,G	UNCERTAIN	REACTS VIOLENTLY WITH ALCOHOLS, CHARCOAL, ORGANIC REFUSE; USED TO MANUFACTURE EXPLOSIVES
	MERCURY-CADMIUM TELLURIDE	G,P	UNCERTAIN	MAY PRODUCE SAME HAZARDS AS THE ELEMENTS: DEATH WITHIN DAYS OF CHRONIC EXPOSURE; ABSORBED AS A LIQUID OR VAPOR; MAY CAUSE BRONCHOPNEUMONIA

P = PARTICULATE L = LIQUID S = SOLID G = GAS

An important issue to emphasize is that the hazards are partially dictated by the experimental procedure. To minimize these hazards, the procedure for each experiment must be known and it must be reviewed by the experimenters, scientists and engineers not assigned to those experiments. This outside review is necessary to ensure that the experiment will take place as written, and to ensure that there are no unforeseen reactions within the experiment. A qualified review from IWFS personnel is also required to ensure compatibility between the chemicals, methods of dumping, and the IWFS components. The currently available information does not provide sufficient information to adequately evaluate the hazards.

Vaguely described chemicals in the experiments (Appendix E) such as "solvents", "wash fluids", "monomers", "cleaning fluids", and "etchant solutions," require further definition and the concentrations of acids and bases must be described more accurately and completely to maintain the integrity of the IWFS. Furthermore, all chemicals must be specified before a dumping protocol can be established.

Particulate control within the USL appears to provide a very big challenge. The problem arises when samples have to be transferred from a work area such as the cutting and polishing module to an area not directly connected. Particles will be transferred in the air surrounding the sample and they will be transferred on the sample, its container, and its holder. Typical glovebox transfer chambers are evacuated and refilled with clean gases but this technique will not guarantee that particulates will be removed in the zero-g environment of the USL. Furthermore, particulates attached to the outermost surface of the sample or its container may not be removed by evacuation and refilling.

Portable transfer chambers present the same shortcoming. There remains a volume in these chambers which can become contaminated by particulates and this chamber is eventually opened to the USL atmosphere. There is no guarantee that the particulates will be removed, and therefore a concern exists that the particulates will be free to invade the USL environment and subsequently be inhaled by the astronauts working in the USL. If the number of particles is very small and they are not hazardous, this might be an acceptable approach. If the particles are beryllium, cadmium, or mercury, then this approach is not safe. Various methods using plastic bags as transfer containers have also been attempted. These systems have not been totally successful.

Another area in which particulate control must be addressed is during the removal of filters. The use of isolation valves that are removed with the filters eliminates the concern with particulates leaving the filter during change-out. However this approach is more costly in terms of dollars, weight, and complexity. Each application will need individual study.

The use of the glovebox indicates evacuation to 1×10^{-3} torr as an atmosphere cleaning mechanism. Normal rubber gloves would have to be much thicker to withstand this pressure differential and that would make them difficult to use. A fluids glovebox concept is provided in Section 7.5.5 which overcomes this problem. The triple seal concept has been required for use, but no description of how materials will be manipulated through these seals is available.

There are some specific hazards in the experiments associated with long storage time and cross reactions with other experiment effluents. The directional solidification experiment uses nitric and hydrochloric acids. Separately they attack many metals but together, in the proper concentrations and proportions, they make aqua regia, which will attack nearly all metals. This acid could be particularly hazardous to valves, pumps, and other components.

The directional solidification and vapor phase crystal growth experiments use mercury fulminate, an extremely shock-sensitive explosive.

The continuous flow electrophoresis experiment lists sodium azide as a required chemical. If this is put into aqueous solution at pH less than 7, hydrazoic acid can be produced. This gas explodes violently even under volume expansion.

Some more general chemical hazards include hydrofluoric acid, which attacks glass and could present a hazardous condition over a long period of time, and freon which can result in an explosion on a fresh aluminum surface with a small shock. Creation of new surfaces (ampule breaking) can produce charge separation and result in a spark. The lower explosion limits of gases such as carbon monoxide, hydrogen, toluene, acetone, acetylene, and methane should be considered before these situations are finalized.

Cross-reactions between the experiment wastes need to be considered carefully in the dumping protocol. There are too many unknown chemicals to define the protocol in this study, but it must be established for the initial USL experiments and it must be reviewed whenever chemicals, concentrations, volumes, or temperatures are changed.

7.5 EXPERIMENT CONFIGURATION

In this study, six particular experiment configurations were explored. These configurations are shown in Figure 7.5-1, and they are individually discussed in Sections 7.5.1 through 7.5.6.

"Typical" Experiment

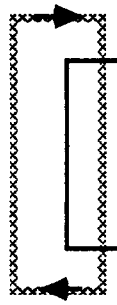

Figure 7.5-1a
Nitrogen used as atmosphere is recycled to minimize resupply requirements. Helium may be recycled from gas stream through teflon tube or membrane.

Acoustic Levitator and Crystal Growth Experiments

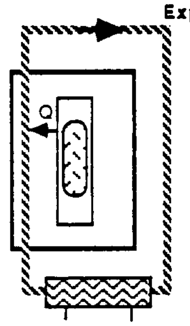

Figure 7.5-1b
Water used as coolant indirectly cools ampule and interfaces with station internal thermal control subsystem

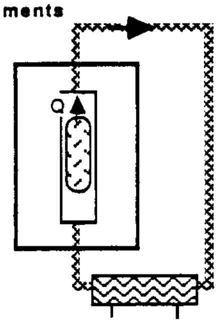

Figure 7.5-1c
Nitrogen used as coolant directly cools ampule and interfaces with station internal thermal control subsystem

Continuous Flow Electrophoresis Experiment (CFES)

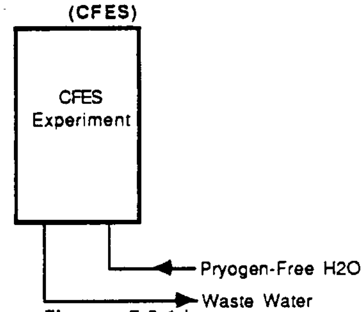

Figure 7.5-1d
CFES experiment interfaces with waste liquid processing system to minimize water requirements.

Fluids Glovebox Concept

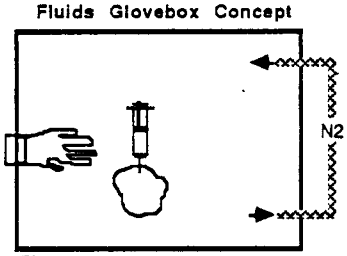

Figure 7.5-1e
A glovebox is used to mix and transfer liquids. A syringe may be used in the transfer processes to contain the liquid. Nitrogen is filtered and recycled.

Cutting and Polishing Facility

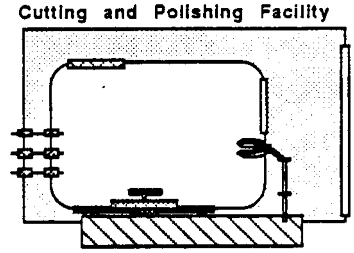

Figure 7.5-1f
A cutting/polishing experiment box concept uses a disposable liner assembly to minimize the potential for release of hazardous materials.

Figure 7.5-1 Typical Experiment Configurations in the USL

7.5.1 Typical Experiment

A "typical" experiment in any of the international laboratories has an atmosphere surrounding the experiment equipment and samples. The fluids glovebox, for example, will require an inert atmosphere to eliminate reactions between the atmosphere and samples or solutions during transfer or in the event of accidental release of fluids from their containers. Normally, however, the highest concentration of vapors will be limited to the vapor pressure of the liquid evaporating as a function of the temperature and rate of vaporization, so the quantities to be removed to purify the gas are small. The simplest concept is to use nitrogen gas as the inert atmosphere and charcoal or other sorbents (see Section 7.9.1) to remove the vapors.

The atmosphere listed for seventeen of the facilities used in the 14 experiments is described as air. These facilities are listed in Table 7.5-1. The requirement for air in each of these facilities should be evaluated considering the effort and expense necessary to produce artificial air (80% nitrogen, 20% oxygen) on orbit, and that many materials will oxidize or form oxide coatings in an oxygen atmosphere. Air will also support combustion whereas a nitrogen atmosphere will not.

Table 7.5-1 USL Facilities Requiring "Air"

Facility	Purpose
Acoustic Levitator	To (re)fill facility
Sputter Deposition Unit	None stated
Steam Autoclave	None stated
Small Bridgeman	To (re)fill facility
Gas Chromatograph	None stated
Electromagnetic Levitator	To (re)fill facility
Electroepitaxy Crystal Growth	To (re)fill facility
Fourier Transform IR	None stated
Free Surface Phenomena	None stated
Membrane Production	Non stated
Alloy Solidification	To (re)fill facility
Solution Crystal	None stated
Differential Scanning Calorimeter	None stated; requires oxygen
Protein Crystal Growth	None stated; requires oxygen
Incubator	None stated; requires oxygen
Droplet Spray Burning	None stated; requires oxygen
Solid Surface Burning	None stated; requires oxygen

The last five of the experiments seem to require oxygen, but the purpose in the differential scanning calorimeter and the protein crystal growth facilities is not known. Therefore, the substitution of nitrogen for air was assumed to be feasible in all but the last three facilities: the incubator, the droplet spray burning, and the solid surface burning.

If nitrogen can be used in place of air, savings will be realized by eliminating the need to produce oxygen on-orbit and by recirculating the nitrogen atmosphere in many facilities. In addition to the facilities listed in Table 7.5-1, there will be liquid nitrogen boiloff from the gas chromatagraph, fourier transform infrared spectrometer, and scanning electron microscope. The nitrogen should be clean and could be directly compressed into a storage tank as illustrated in Figure 7.5-2. Fresh nitrogen from Space Station storage would be used for make-up if the recirculating nitrogen supply became contaminated and could not be used.

To preclude contamination, the recirculating nitrogen will pass through activated charcoal or other sorbents, as required, and molecular sieve or Drierite will be used to remove water. The system will be monitored by the same mass spectrometer proposed for the waste gas system. When the adsorbent materials are regenerated, the effluent will be dumped to the waste gas system.

The purge of the transfer chamber will probably need to be dumped to the waste gas system because it may be designed to be opened to the USL atmosphere and this will introduce oxygen into the recirculation system. An alternative is to use a getter to remove oxygen (or any other available technique) and then to recirculate the deoxygenated gas in the nitrogen recirculation system.

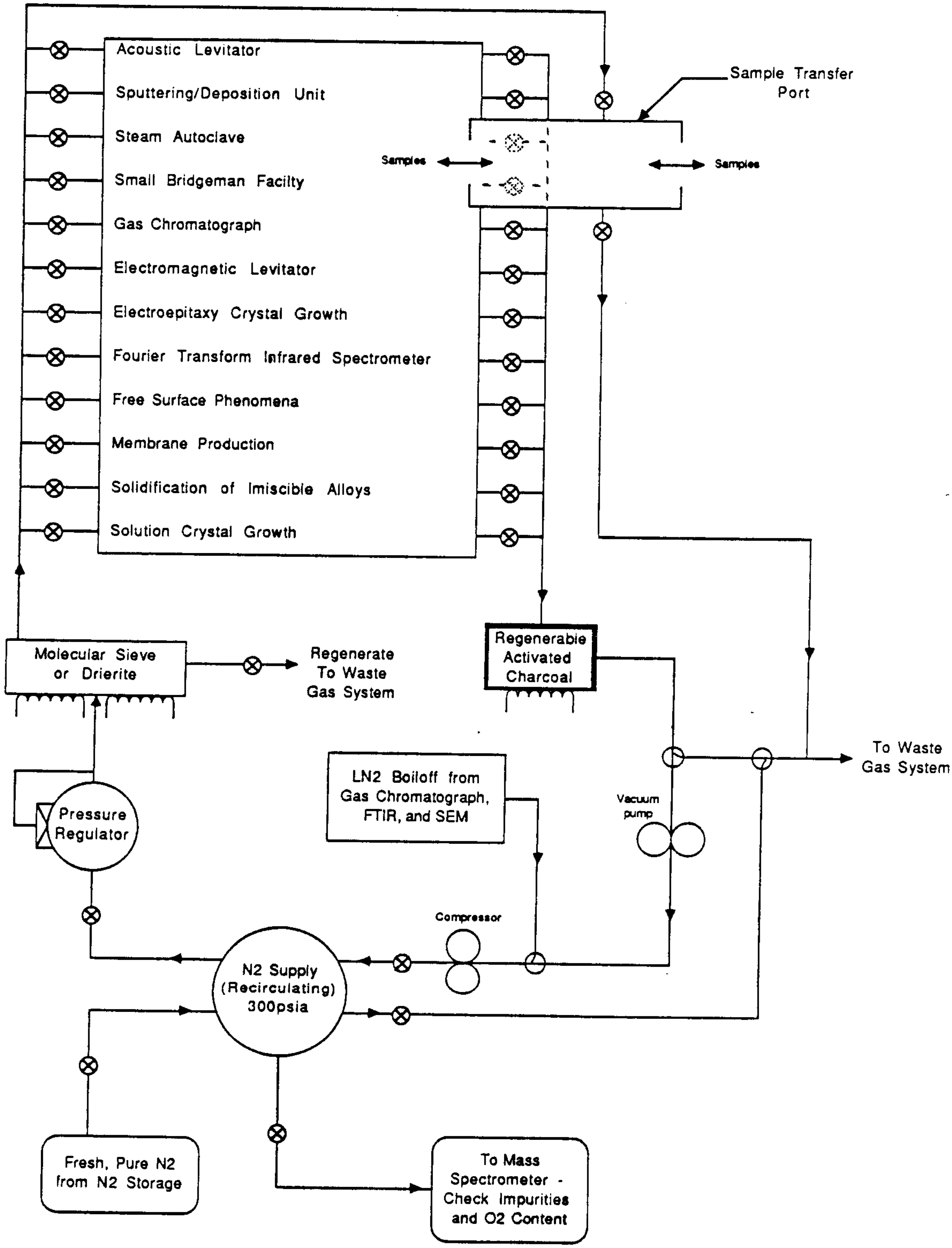

Figure 7.5-2 Nitrogen Recirculation System

7.5.2 Water as a Coolant

One option for cooling experiments is presented in Figure 7.5-1b. Water is used to indirectly cool the experiment while remaining isolated from any reactions and chemicals to preclude contamination. Heat can be removed from the water through a heat exchanger which interfaces with the station internal thermal control system (TCS) or through the use of a thermoelectric heat pump.

7.5.3 Inert Gas as a Coolant

An alternate means of cooling experiments is the use of inert gas, as shown in Figure 7.5-1c. In this concept, the inert gas (e.g., nitrogen) directly cools the ampule. The heated inert gas can be cooled through the use of a heat exchanger interfacing with the TCS.

7.5.4 Pyrogen-Free Water

Some of the experiments, such as the Continuous Flow Electrophoresis in Space (CFES), require the use of pyrogen-free water. Pyrogens consist of polyliposacharrides derived from cell walls. These contaminants can adversely affect many biochemical processes and must be completely removed. The waste water handling system processes the waste water from experiments such as CFES and provides pyrogen-free water to all users.

7.5.5 Fluids Glovebox Concept

The fluids glovebox provides a facility for the safe transfer and handling of liquids and solids in a zero gravity environment. The glovebox must provide containment of the materials being handled and the capability for cleanup should any fluids be accidentally released.

Past glovebox concepts have had a major problem associated with venting the glovebox. The designs have typically incorporated the feature of being vented to remove any contaminants. The problem lies in the impact of venting on the glove portion of the box. The gloves will be pulled into the box during venting operations.

Another problem with previous glovebox concepts is the handling and transfer of liquids and liquid/gas separation.

The recommended glovebox concept, illustrated in Figure 7.5-3, addresses the problems of the previous concepts. The glovebox is equipped with a port which provides a chamber in which to retract the gloves during venting operations. The hatch can be closed and latched as the glove is retracted into the chamber. This concept allows the glovebox to be vented without rupturing the gloves. An integral ring and seal simplify replacement of gloves should this be necessary. A self-sealing plastic bag, attached externally to the glove port, is used in the replacement of gloves.

Handling and transfer of liquids in the glovebox is accomplished with the use of fluid containment bags and syringes. The fluid containment bags are provided with septums to allow the use of syringes to transfer precise quantities of fluids into and our of the fluid containment bags. Quick disconnect (QD) type connections will be provided as a feature of the bags to allow interface with the waste liquid collection and handling system. The fluid containment bags eliminate the need for phase separators and provide an additional level of containment for hazardous liquids.

(Profile View)

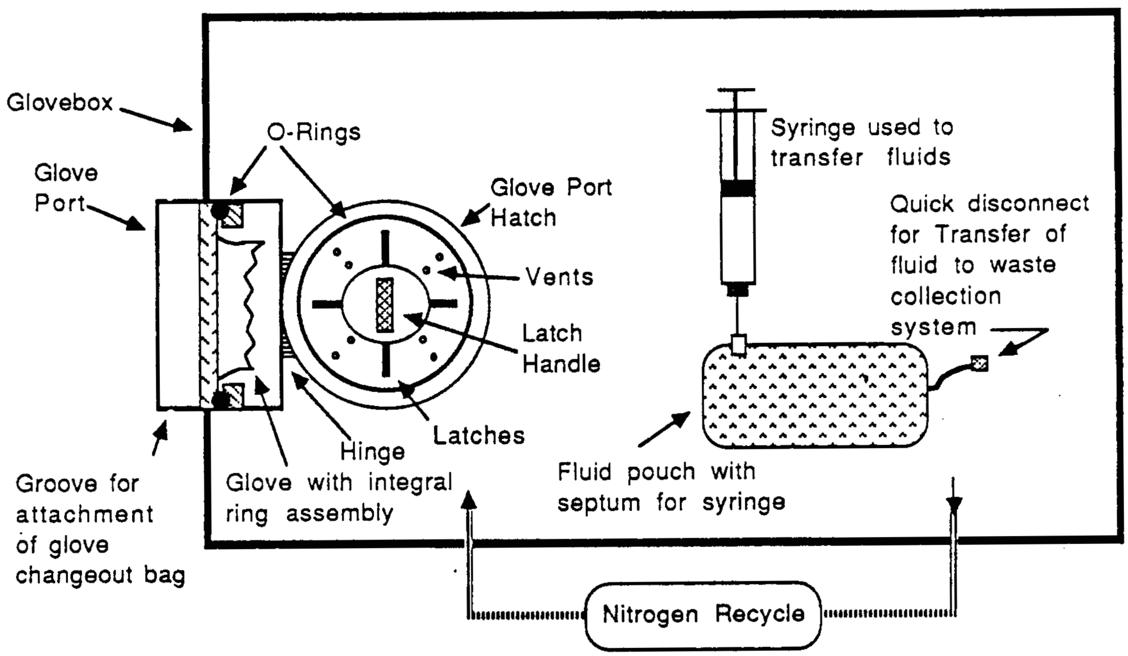

Figure 7.5-3 Fluids Glovebox Concept

7.5.6 Cutting and Polishing Facility

The cutting and polishing facility provides the capability to open ampules, cut and polish samples, and perform etching procedures to support characterizing experiment samples such as those produced by the acoustic levitator and crystal growth experiments. This facility must provide an uncontaminated environment (i.e., not contaminated by previous operations) for these activities, and must preclude the release of contaminants into the station atmosphere. An interface with the waste gas system provides the capability to evacuate the box. Other fluids used in the cutting and polishing facility include nitrogen, or other inert gases, and water used for lubrication cooling and removal of particles in the cutting and polishing operations.

Problems with the cutting and polishing facility concepts have included separation of multiphase materials, as well as cleaning and decontamination procedures. An approach to the design and operation of this facility which eliminates these problems has been developed.

The proposed cutting and polishing facility (Figure 7.5-4) uses a collapsible, disposable liner assembly with integral access port, hydrophobic particulate filter, fluid connections, and cutting and polishing heads. The liner, which prevents the box itself from being contaminated, also has "gloves" to accommodate the remote manipulator. Positive pressure in the liner assembly keeps the liner inflated and forces air through the particulate filter. The liner assembly retains particulates and has an interface for removing waste liquids. A bag assembly interfaces with the access port for removing the sample without releasing contaminants. After use, the entire liner with cutting and polishing heads is removed and replaced with a clean liner assembly for the next use.

The cutter concept and a sample holder concept are illustrated in Figure 7.5-5. One of the pulleys is driven via the magnetic coupling. The cutting wire rotates about the drive pulley and an idler pulley. A liquid nozzle, shown on the left, wets the cutting wire to provide lubrication, cooling, and particulate removal. The shroud on the left houses the nozzle and prevents excessive

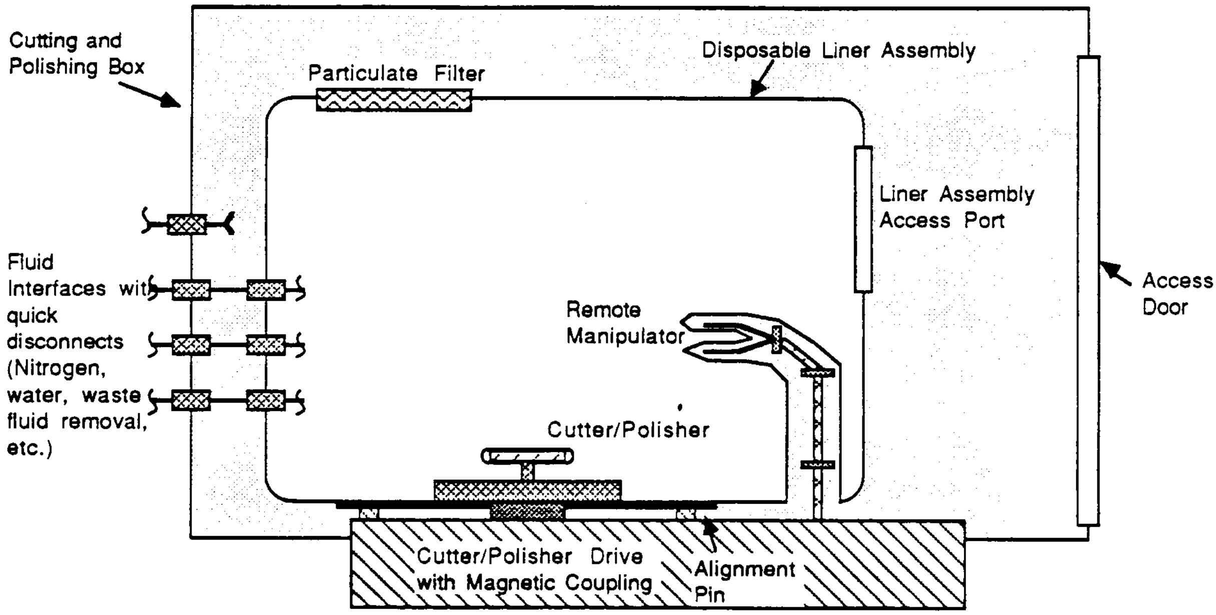

Figure 7.5-4 Cutting and Polishing Facility Concept

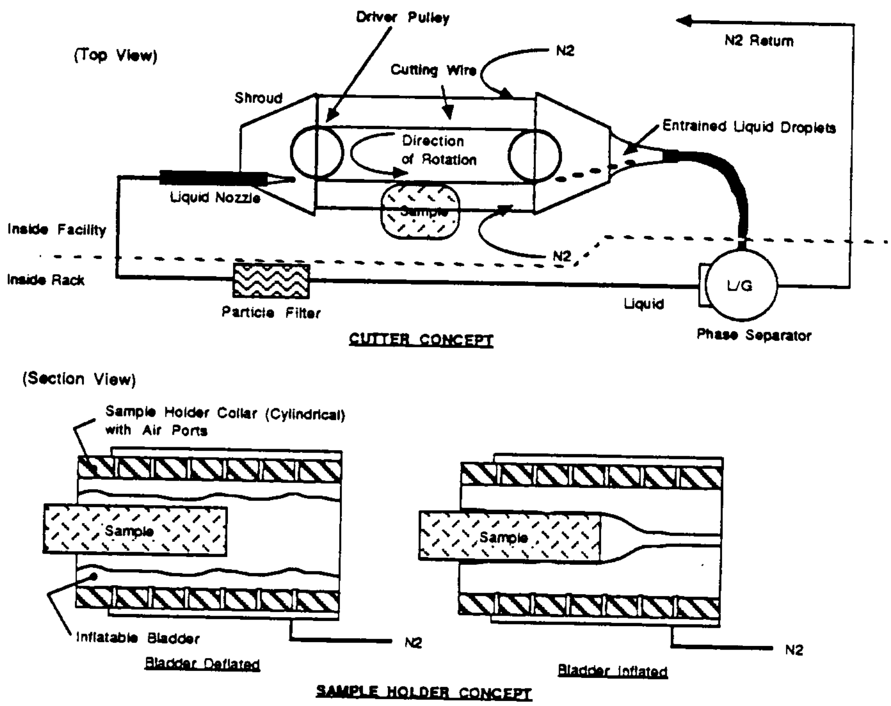

Figure 7.5-5 Cutter and Sample Holder Concept

overspray. The liquid is removed at the shroud on the right by entrainment in a nitrogen stream. The liquid is separated from the nitrogen by a phase separator (centrifugal-type), filtered, and reused. The nitrogen is returned to the experiment box.

The proposed sample holder is a cylindrical collar containing an internal bladder assembly. Nitrogen inflates the bladder, securing the sample in the collar. The collar can be held and manipulated by the robotic manipulator for cutting and polishing operations without exerting unnecessary pressure on the sample.

7.6 VENTING THROUGH RESISTOJETS

7.6.1 Contamination Requirements/Restrictions/Considerations

Contamination control requirements were established based on the "Space Station External Contamination Control Requirements, JSC 30426"[13]. The resistojet venting system will be required to operate only during non-quiescent periods (i.e., when the Shuttle is docked at the Space Station).

Contamination requirements set no limit on the temporary column density during non-quiescent periods. Column density is defined as the number of molecules per unit area that exist along the line of sight used by an experiment. Although no temporary column density limit is set, the contaminant deposition level on sensitive surfaces is limited to 4×10^{-7} g/cm^2/-yr(8.2×10^{-7} lbm/ft^2-yr).

The types of waste materials that can be vented through the resistojet system are limited by considerations of safety, corrosion, and contamination by particles or droplets. Table 7.6-1 contains the list of materials that can be vented using the resistojet system. Table 7.6-2 is a list of some materials that should not be vented. Table 7.6-2 also contains comments about why these materials should not be vented.

7.6.2 Resistojet Operation

The resistojets will operate during non-quiescent periods only, disposing of waste fluids and simultaneously providing thrust for reboost of the Space Station.

7.6.3 Resistojet Venting Concerns

A concern with the resistojet venting system is possible contamination due to backflow from the resistojet nozzles. Calculations agree with Rockwell's results documented in "NASA Contractor Report 180832"[14] that the gases will be expanded close to the free molecular flow regime so that backflow will be slight. Experimental data from NASA/Lewis reported in AIAA-87-2121[15] show a plume density less than 5.6×10^{-5} molecules/cm^{-3} (9.2×10^{-6} molecules/in^3) at angles less than or equal to 85 degrees off axis for distances less than or equal to 32 centimeters (1.05 ft) from the nozzle. This is for CO_2 at a chamber temperature of 300°K (80°F), chamber pressure 20 psia, and flow rate 0.2 g/s (4.4×10^{-4} lbm/s). The exit velocity of the CO_2 is estimated as 1984 m/s for a chamber temperature of 1400°C, (2552°F) and this velocity is used to estimate the mass flux rates which would occur in normal operation with this chamber temperature. On the reasonable assumption of an inverse square relationship between distance and density, the total incident mass flux at 8 meters (26 ft) from the nozzle and 85° off axis would be within the acceptable limit for deposited material on the Space Station. For the vented gases, the mass deposited on a surface is much less than the incident flux (except for cryogenic surfaces, where it can be nearly as large as incident flux). Also, backflow is expected to be much less than flow at 85° off axis.

Table 7.6-1 Materials Acceptable for Resistojet Venting

Noble Gases

Helium
Neon
Argon
Krypton
Xenon
Nitrogen
Oxygen
Water Vapor
Carbon Dioxide

Figure 7.6-2 Materials Not Acceptable for Venting Through Resistojets.

Material that Cannot be Vented (Partial List)	Comments
Particulates, droplets and fluids with low vapor pressure	- May result in deposition on exterior surfaces
Undefined materials (i.e., solvents)	- Constituents unknown
Mercury and materials containing mercury (such as HgCdTe)	- High toxicity, corrosive behavior toward aluminum alloys, and severe contamination effects on optics, plus relatively high vapor pressure (for a metal)
Halogens and ammonia	- Corrosive effect on grain stabilized platinum in resistojets
Freon	- Possible corrosion of the resistojet system at high temperatures
Organic compounds including	- Requires resistojet operation at inefficiently low temperatures to prevent carbon deposits - Proposed system removes organic compounds or converts them to ventable gases with the exception of the CO_2/CH_4 mixture from the ECLSS - Proposed system could use catalytic converter to combine mixture with oxygen to get carbon

From the above discussion, it is concluded that backflow from a properly designed and operated resistojet venting system will be insignificant, however, the data is preliminary and requires further investigation. Recent tests performed at Arnold Engineering Development Center[16] indicate more backflow from resistojets than the original NASA/Lewis experimental data show. These differences have not yet been resolved. Additional experimental work is being performed by R. Tacina at NASA/Lewis, and mathematical modeling is being performed by B. Riley of the University of Evansville under NASA contract.

Analitical data established through a Martin Marietta proprietary technique (IR&D Project D-08D, "Rocket Exhaust Contamination") agree with Rockwell's results in "NASA Contractor Report 180832" that the vented gases will not condense in the nozzle. No condensation of any of the vented gases is expected unless the gases impinge on a cryogenic surface.

The resistojets must be located downwind of any sensitive surfaces. Otherwise, molecules of vented material could collide with molecules of the natural atmosphere and be scattered (bounced) back to the sensitive surfaces. Preferably, resistojets should be located downwind of insensitive surfaces also, since contamination can potentially be transported between surfaces. Also, the resistojets should not be operated at higher pressures or lower temperatures than planned, or unacceptable backflow may occur.

7.7 VENTING TO SPACE THROUGH THE VACUUM VENT SYSTEM

7.7.1 Contamination Requirements/Restrictions

The contamination control requirements are established in "Space Station External Contamination Control Requirements, JSC 30426"[13]. The vacuum venting system will be required to operate during quiescent periods (i.e., when experiments requiring clean lines of sight may be in operation).

The contamination requirements set limits on the column density during quiescent periods. Column density is defined as the number of molecules per unit area that exist along the line of sight used by an experiment. The limits are 10^{11} molecules/cm^2 (6.5×10^{11} molecules/in^2) of infrared-active molecules and 10^{13} molecules/cm^2 (6.5×10^{13} molecules/in^2) each for O_2 for N_2, for H_2, for total noble gases, and for all other molecules combined. The grand total allowable is 5.0×10^{13} molecules/cm^2 (3.2×10^{14} molecules/in^2). Also, the contaminant deposition level on sensitive surfaces is limited to 4×10^{-7} g/cm^2-yr (8.2×10^{-7} lbm/ft^2-yr).

The types of materials that can be vented through the vacuum vent system are limited by considerations of safety, of corrosion, and of contamination by particles or droplets, as explained in Section 7.7.6 and 7.7.7 below.

7.7.2 Reference Configuration for Vacuum Vent System Operation

The vacuum venting system is required to vent chambers of about one cubic meter (35 ft^3) volume each. The pressure in the chamber is 0.25 Torr (0.0048 psia) when the vent is opened and 0.001 Torr (1.9×10^{-5} psia) when the vent is closed again. The reference configuration of the vacuum vent line is a 120 foot long, 6 inch diameter tube.

7.7.3 Flow Characterization in Vent Line

The vacuum vent system starts operating when the pressure in the experiment chamber reaches 0.25 Torr (0.0048 psia) and stops venting when the chamber pressure drops to 0.001 Torr (1.9×10^{-5} psia). At the lower pressures (about 0.004 Torr or 7.7×10^{-5} psia and less) the gas flow is "free molecular," meaning that the molecules move individually without having much influence on each other. At the higher pressures (up to 0.25 Torr or 0.0048 psia) transition flow occurs, meaning that the gas behaves as a coherent fluid but does not obey the same fluid flow laws which hold at high pressures. If the gas is allowed to vent as a coherent fluid from 0.25 Torr (0.0048 psia) to free space, the layer of gas flowing along the wall will turn sharply outward when it reaches the end of the vent. This will cause a backflow toward the Space Station. If free molecular flow is maintained at the outer end of the vent tube, then the gas molecules will follow straight lines, and their paths will be within 90 degrees of the tube axis as they leave the vent tube.

7.7.4 Vent Line Sizing Based on Free Molecular Flow

The "plume" of gas from a vent tube is not as directional as that from a nozzle. To prevent significant backflow from occurring, the pressure at the end of the vent tube will have to be within the free-molecular range. The criterion that mean free path is greater than or equal to the tube radius requires pressures below 0.0044 Torr (7.7 x 10^{-5} psia) for a 6" diameter vent tube.

Quickly opening a full-size valve from chamber to vent could result in exceeding this pressure limit, causing backflow of vented gases to the Space Station. A properly sized opening for the flow control valve from the chamber to the vent tube would be one which passes vented gas into the tube at the same rate that gas at 0.004 Torr (7.7 x 10^{-5} psia) can exit the tube into a vacuum. Using data and equations from Dushman & Lafferty's book [17] (see Table 7.7-1) for air flowing through orifices at 77°F (25°C), and assuming a 6" diameter vent, the safe size opening at the chamber end turns out to be about 3/8" (1 cm) diameter. As the chamber pressure drops, the opening can gradually be enlarged. The analysis used to estimate the opening size is conservative. Detailed analyses of transient flow for specific geometries might permit larger openings and, of course, the opening can gradually be enlarged as the chamber pressure decreases.

7.7.5 Required Venting Time Based on Free Molecular Flow

The theoretical steady-state free-molecular (slowest case) venting time can be calculated by integrating the equation Q = KP, where Q is the gas flow rate in m^3-Torr/s, K is the gas flow conductivity in m^3/s, and P is the pressure in Torr (see Table 7.7-1 for units conversion factors). With the chosen units, dP/dt=-KP in a chamber having a volume of 1 cubic meter (35 ft^3). Therefore, dt = -(1/K)d(ln P) so that, for constant K, the vent time is $(1/K)\ln(P_{initial}/P_{final})$. For a pressure drop from 0.25 Torr (0.0048 psia) to 0.001 Torr (1.9 x 10^{-5} psia), for air at 25°C (77°F), through a tube 120 ft long and 2" in diameter, vent time is about 3-1/2 hours. For a tube with a diameter of 4", venting takes about 26 minutes. Estimated vent times for various vent line configurations are presented in Table 7.7-2. (Note that K is inversely proportional to tube length and directly proportional to the cube of the tube diameter as shown in Table 7.7-1.)

7.7.6 Vacuum Venting Concerns

There are many concerns associated with the present vacuum vent concepts including the following:

1) Any harmful materials accidentally released within a vacuum system during venting will enter the vent system.

2) It will be difficult to effectively prevent particles from entering the vent system. The larger particles vented may move slowly and thus may strike Space Station surfaces or intersect lines of sight of experiments requiring a clear optical field. (Slow moving particles were observed returning to Skylab surfaces after ejection from elsewhere on the Skylab.)

Approaches to particle removal include electrostatic precipitators and filtration. Electrostatic precipitators require some gas pressure, require periodic cleaning, and cannot remove all particles. Filters cause a pressure drop and the maximum pressure of 0.25 Torr is only 0.005 lbf/in^2.

3) With routine vacuum venting, there is no effective central knowledge or control over the materials vented. Many noxious, toxic, irritating, carcinogenic, and corrosive materials will be handled in the laboratories.

Table 7.7-1 Equations Used to Calculate Vacuum Venting Times

Flow conductivity

$$K = Q/P$$

where
- K = flow conductivity, m^3/s — ($1\ ft^3/s = 0.0283\ m^3/s$)
- P = pressure difference, Torr — (1 psia = 51.7 Torr)
- Q = gas flow rate, Torr-m^3/s — (1 psia-ft^3/s = 1.464 Torr-m^3/s)

Venting time

For venting a 1 cubic meter (35 ft^3) chamber of air to vacuum, using the above units,

$$dP/dt = -KP$$

so that for constant K the vent time is:

$$T_{vent} = (1/K)\ \ln(P_{initial}/P_{final})$$

Conductivity of an Orifice

The conductivity K of an orifice is:

$$K_{free\ molecular\ flow} = 0.25\ V_a A$$

$$K_{transition\ flow} = (K_{free\ molecular\ flow})$$

where
- V_a is the average molecular velocity from kinetic theory
- A is the orifice area
- P is the pressure in Torr (1 psia = 51.7 Torr)
- a is the orifice radius in cm (1 in = 2.54 cm)

Conductivity of a Vent Tube (with circular cross section)

The flow conductivity K through a vent tube is:

$$K_{free\ molecular\ flow} = (2/3)\quad (a^3/1)\ V_a$$

where
- a is the vent tube radius
- 1 is the vent tube length

Table 7.7-2 Venting Times for Various Vent Line Sizes

Vent Line Diam (in)	Vent Line Length (feet)	Connection To Vent Line	Overall Conductivity (m^3/sec)	Overall Conductivity (ft^3/s)	Time Required to Vent (minutes)
2	120	Direct to vent line	0.000438	0.0155	210.
4	120	Direct to vent line	0.00359	0.127	26.
4	120	2 in. dia. 6 ft. long	0.00250	0.088	37.
6	120	Direct to vent line	0.01183	0.418	8.
6	120	2 in. dia., 6 ft. long	0.00503	0.178	18.

Note: Vent times calculated assuming free molecular flow (conservative)
- Conductivities are for free molecular flow
- 1 cubic meter (35 ft^3) of air at 25°C (77°F) vented from 0.25 Torr (0.0048 psia) to 0.001 Torr (1.9×10^{-5} psia).
- Conductivity in vent tube is proportional to cube of radius and inversely proportional to length

4) Excessive column densities persisting for tens of seconds may occur due to venting (depending upon the relative positions of the vent and the experiment line of sight, and upon the particular gas being vented). The initial venting rate for air through the 3/8" opening described in Section 7.7.4 above is 13 mg/s (2.9×10^{-5} lbm/s), and the chamber could initially contain about 390 mg (8.6×10^{-4} lbm) of air.

5) The impulse due to venting may be significant, since reduction of vibration, shock, and unwanted thrust is desirable. One cubic meter (35 ft^3) of air at 25°C (77°F) and 0.25 Torr (0.0048 psia) weighs 0.39 gram (8.6×10^{-4} lbm), and its sonic speed when vented is 346 m/s (1135 ft/s). The momentum is 0.135 kg-m/s or 0.135 N-s or 0.030 lbf-s for each venting.

6) Many chemicals to be used in the laboratories have not been defined. They must be characterized as to chemical and physical properties before plans can be made to control them. "Cleaning solutions" and "solvents" are not satisfactorily defined and cannot be allowed in the vacuum vent system.

7.7.7 Recommended Approach for High Quality Venting System

Concerns 1 through 5 above could be avoided by pumping the vacuum chamber all the way to 0.001 Torr (1.9×10^{-5} psia) using the regular vacuum pumps (which vent through the resistojets). The vacuum vent system could then be reserved for emergencies and optimized for emergency service.

Emergency venting must take place if an accidental chamber pressure increase threatens injury to personnel. Venting in an emergency mode must not take place otherwise, because unnecessary and possibly severe contamination could result. Design of an emergency vent system would be more easily optimized if the system did not also have to vent routinely.

An emergency system could involve a panel (between chamber and vent line) which is mechanically pushed open (or possibly shattered) on instructions from a central microcomputer control which decides when a dangerous situation (such as rapid pressure increase) requires emergency venting. This decision process could be tailored to each experiment.

Emergency equipment and procedures must be provided in case of accidents involving particularly hazardous materials (examples: mineral acids, mercury, acetonitrile, beryllium, chlorine, iodine, mercury amalgams/alloys such as HgCdTe, and mercury compounds such as HgI_2).

Mercury and its compounds and alloys require special attention because of relatively high volatility, high toxicity, severe contamination effects on optics, and corrosive behavior toward aluminum alloys. Beryllium-containing materials also require special attention because their dusts, particulates, and chips small enough to be swallowed or inhaled are a serious toxicity and carcinogenicity hazard.

Precautions must be taken to prevent accidental release of materials into the venting system (e.g., from furnaces into thermally insulating vacuum spaces around them).

7.8 REFERENCE INTEGRATED WASTE FLUID SYSTEM CONFIGURATION

7.8.1 Overview of Integrated Waste Gas Handling System

The reference Integrated Waste Gas Handling System, shown as part of Figure 7.8-1, provides a means of evacuating rack-mounted experiments via a combined waste gas collection/vacuum vent system. A vacuum pump, colocated with the waste gas processing equipment, provides the "rough vacuum" to 5×10^{-3} psia (0.25 torr) and collects waste gases from the experiments. The vacuum vent system provides the capability to vent the experiment to space vacuum and provide 2×10^{-5} psia (10^{-3} torr) in the experiments when required.

Regenerable sorbent beds are used to remove most of the organic contaminants in the waste gas. Two of these beds are located in parallel to allow desorption of one bed as the other is adsorbing. Desorption is accomplished through the use of elevated temperature. A gas analyzer or monitor, located downstream of these two beds, is used to check for breakthrough of the beds. A third sorbent bed is located downstream of the first two beds as a precaution in the event of bed breakthrough.

After passing through the sorbent beds, the gas is passed through a catalytic oxidizer to convert extremely low-level contaminants which have not been captured by the sorbent beds to gases compatible with the resistojets. A compressor, downstream of the catalytic oxidizer, raises the pressure of the gas to the required storage pressure. The gases are then cooled and a gas/liquid separator removes condensed liquids and transfer them to the waste waste handling system. The gases are passed through a desiccant to reduce the dewpoint to a temperature compatible with transfer to resistojets external to the station.

The processed gases are stored in a storage tank, where a final analysis is performed to insure compatibility of the gases with the resistojet and to quantify the gases for specific impulse calculations. If the gases fail this analysis, they are transferred via the three-way valve back to the inlet of the processing system.

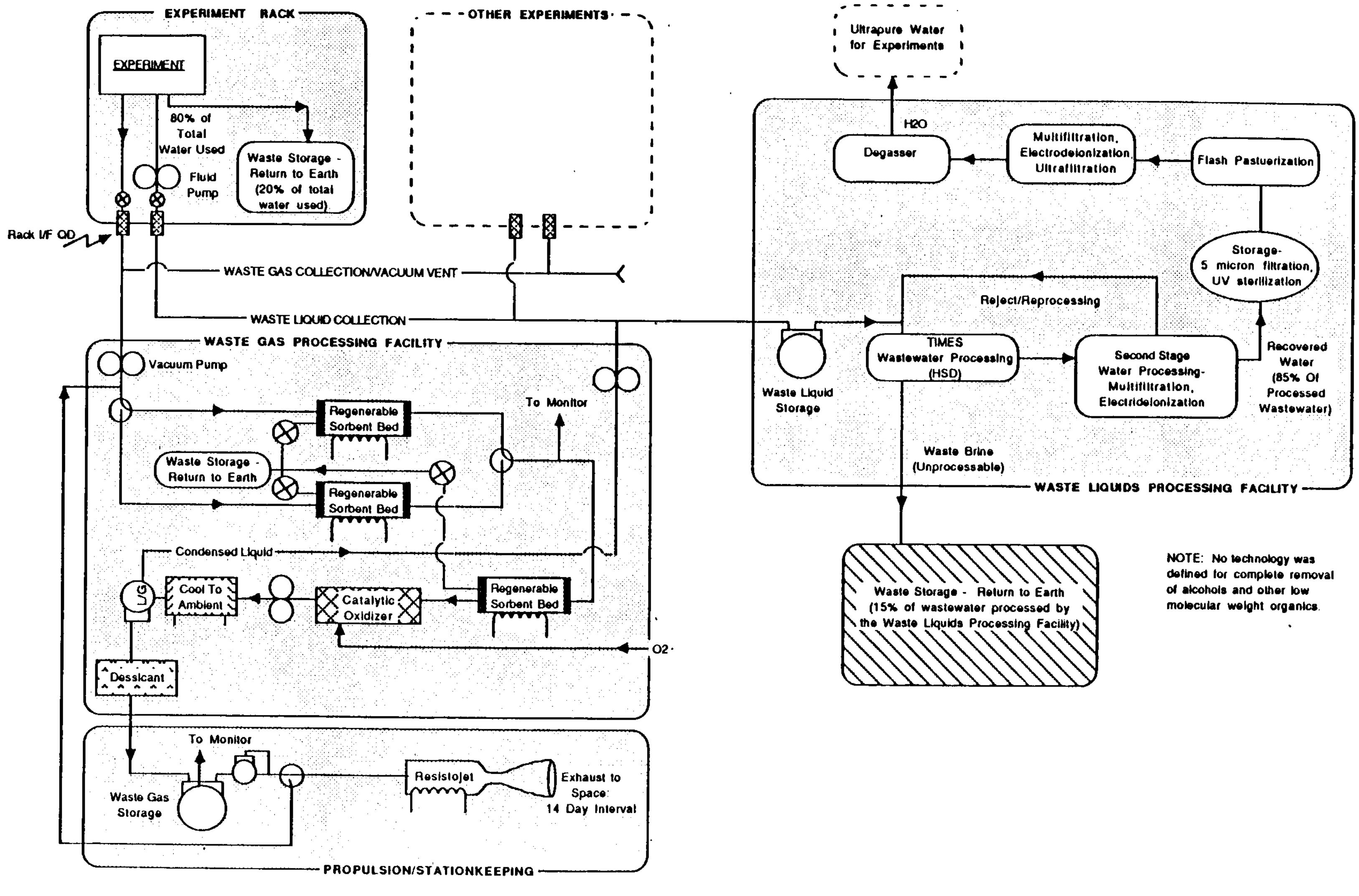

Figure 7.8-1 Revised Reference Configuration for the Integrated Waste Fluid System

7.8.2 Overview of Integrated Waste Water Handling System

The Waste Liquid Handling System reference configuration, also shown in Figure 7.8-1, performs the function of recovering usable water from the experiment liquid wastes. Fluid pumps in the experiments transfer the waste liquids to the handling system via the waste liquid collection system. The liquids are stored in a waste liquid storage tank which acts as an accumulator to smooth out transients in flow. The liquids then continue to the TIMES (Thermoelectric Integrated Membrane Evaporation Subsystem,[18] for processing. The eject, or brine, from the TIMES processor will be stored and returned to earth. The quantity of brine is expected to be approximately 15% of the total waste water processed by the TIMES.

The water recovered by the TIMES continues to a second-stage processor which uses a combination of multifiltration and electrodeionization (or continuous ion exchange, CIX,[21]). Reject from this second stage processing is recycled back to the inlet of the TIMES.

The recovered water (estimated as 85% of the total waste liquid processed) is filtered through a 5 micron filter, sterilized using ultraviolet (UV) light, and is held in a storage tank. The next stage in processing is flash pasteurization, or a temperature cycle, followed by multifiltration and electrodeionization. The final product water is degassed and is then ready for use by experiments.

There are several problems with this reference configuration. One problem is the requirement for liquid/vapor separators and fluid pumps in the experiments. It is anticipated that such rotating equipment in the experiment racks may adversely impact the microgravity environment.

Another problem is the removal of alcohols and other low molecular weight organics from the waste water. No technology has been identified for this purpose in the reference configuration.

7.8.3 Storage System Sizing Based on Various Storage Pressures

After careful inspection of elements contributing to the waste fluid system and a more thorough understanding of the capabilities within the waste system, a revised integrated waste fluid inventory was established as presented in Table 7.8-1. The initial waste gas storage volume requirement was sized to accommodate 30 days of storage for the inert effluents from the experimental laboratories which amounts to 185.4 lbm of contributing gases requiring 31.8 ft^3 of volume at a pressure of 1000 psia. The gases to be stored are primarily the permanent gases such as N_2, H_2, O_2, etc., with only a minimal amount of CO_2 coming from the catalytic oxidizer. The volumetric storage requirements for pressures ranging from 100 to 1000 psi (6.9 to 69 atm) are presented Table 7.8-2.

The storage tank will be placed on the outside of the USL where the temperatures may range from -148° to +212°F (-100 to +100°C). A item of concern when performing a parmetric analysis is the compressibility coefficient, Z, of the gases. The available coefficients[20] for N_2, O_2, and Ar show that if the storage pressure is 7 atm, $Z = 1$ and the gases behave essentially as an ideal gas over the temperature range -100 to 260°F. If the higher storage pressure of 1000 psi (69 atm) is used then Z varies by 22% over the same temperature range, i.e., Z is 0.78 at -100°F and Z is 1 at 260°F. Tank volumes are presented in Table 7.8-2

7.9 INTEGRATED WASTE FLUID SYSTEM SUBSYSTEMS

7.9.1 Sorbent Beds

The sorbent beds serve as the primary protection system for the resistojets. Their purpose is to remove, by adsorption/absorption, the contaminants from the atmosphere of the experiment

Table 7.8-1 Revised Waste Fluid Inventory (lbm/90 days)

Constituents	USL	JEM	COL	ATTACHED PAYLOADS	ECLSS BOSCH	ECLSS SABATIER
INERTS						
Argon	24.3	152.0	152.0	--	--	--
Carbon Dioxide	13.5	11.0	11.0	--	--	--
Freon	--	--	--	--	--	--
Helium	0.8	4.4	4.4	353.2	--	--
Nitrogen	77.2	13.5	13.5	--	--	--
Xenon	8.2	--	--	--	--	--
Krypton	--	9.9	9.9	--	--	--
OXIDIZERS						
Air	39.7	--	--	--	--	--
Cleaning Solution	3.7	--	--	--	--	--
Oxygen	4.5	3.3	3.3	--	--	--
Water Vapor	97.0	--	--	--	--	--
FUELS						
CO2/CH4	--	--	--			
Hydrogen	0.2	0.2	0.2	--	--	957.7
Others	TBD (probably small)	TBD (probably small)	TBD (probably small)	--	38.4	--
				--	--	--
LIQUID WASTES						
Cleaning Solution	158.8	0.0	0.0	--	--	--
Waste Water.	1241.4	0.0	0.0	--	--	--

Table 7.8-2 Tank Volume and Power Requirements as a Function of Storage Pressure

Constituents	Quantity (lbm/30 days)	Tank Volume at Specified Pressures (cubic feet)			Power Requirements at Specified Pressures (kW-hr)		
		300	500	1000	300	500	1000
Argon	109.4	51.9	31.1	15.6	10.67	14.09	20.02
Carbon Dioxide	11.8	5.1	3.1	1.5	0.75	0.93	1.22
Helium	3.2	15.2	9.1	4.6	3.11	4.11	5.84
Nitrogen	34.7	23.5	14.1	7.0	3.90	4.95	6.64
Xenon	2.8	0.4	0.2	0.1	0.08	0.11	0.15
Krypton	6.6	1.5	0.9	0.5	0.31	0.41	0.58
Air	13.2	8.6	5.2	2.6	1.43	1.82	2.44
Oxygen	3.7	2.2	1.3	0.7	0.36	0.46	0.62
Total	185.4	108.4	65.0	32.6	20.61	26.88	37.51

modules. The atmosphere of an experimental module will be evacuated into the Gas Waste Management System and the gas stream will be passed through the sorbent bed in its pathway to the storage tank for use in the resistojets. With the possible exception of the combustion experiments these contaminants will be in low concentrations. Their source is the finite vapor pressure of the liquids used in the experiments. The liquids include such organics as alcohols, Freons, other halogenated compounds, ketones, as yet undefined other cleaning solvents, and inorganics such as mercury, halogens, halogen acids, and hydrogen.

The beds consist of several sorbents, most probably but not necessarily, in series, where each solvent removes one or more of the contaminants for which it has a particular affinity. Although a sorbent is chosen for its particular affinity for a particular compound(s), it may also remove, although less well, compounds for which another sorbent has been chosen. Rather than being detrimental, this can enhance the scrubbing process. For example, silica gel can be used to primarily remove methanol vapor. Activated charcoal can also remove methanol, but not as well.

Some potential sorbents include: activated charcoal for organics including ethanol, toluene, ketones, and halogenated organics; impregnated charcoal for mercury vapor; Mine Safety Appliances proprietary sorbents for chlorine and dimethylsulfoxide; silica gel for HC1, methanol, and dimethylformamide; titanium sponge for hydrogen (up 7.3 gm ending up as TiH1.75); and molecular sieves which are non-specific and theoretically should take up all the contaminants. It should be noted that molecular sieves may adsorb some of the gases which are to be used in the resistojets.

Since the contaminants are in low concentration, it is expected that only infrequent sorbent bed regeneration will be required. Regeneration requires the sorbent bed to be heated or evacuated and the evolving materials be pumped into the waste storage tank for return to Earth at a later time. When regeneration is required, the gas stream will be passed through the second bed. Thus the beds will be alternatively regenerated and used.

The mass spectrometer will be used to monitor the gas stream coming out of the sorbent bed and it will serve to dictate when to change over to the second sorbent bed. This monitoring will also serve to warn against an unforeseen saturation or "break-through" of a sorbent bed.

7.9.2 Catalytic Oxidizer

The catalytic oxidizer is the last step in the clean up of organic vapors from the gas stream prior to storage for use in the resistojets. Its purpose is to oxidize any residual vapors (to carbon dioxide and water) that have not been removed by the sorbent beds.

Catalytic oxidation is well known and requires no new technology. There are, however, no properly sized off-the-shelf systems. Vendors design and fabricate such systems to the requirements provided to them. Potential vendors include Comet (Hiram, OH), Met-Pro Corporation (Harleysville, OH), and Mine Safety Appliances (Pittsburg, PA). No problems are expected for space qualification. The oxidation takes place on a metal foil housed in a support structure. The structure can be designed to give very good structural stability without any decrease in efficiency.

The catalytic oxidizer is expected to have a very long useful life (2 years). Known poisons of the oxidizer (e.g., mercury and halogens) will be removed by the sorbent beds and the concentrations of organic vapors will be very low. These concentrations are expected to be low when they reach the sorbent beds and will be lowered further by the beds themselves.

If the sorbent beds can be optimized, it may be possible to discard the catalytic oxidizer. This is desirable since the oxidizer may require some extra oxygen gas, and it does require power for heating up to required temperatures for the oxidations to take place. For example, acetylene requires it to operate at 350°F, ethanol 500°F, and if methane is present, it would be required to operate at 800°F. Virtually all organics can be oxidized below 900°F. Considerable confidence in the sorbent bed will have to be developed before such a decision can be made, however.

7.9.3 Gas Monitoring and Inventory

A small magnetic type mass spectrometer will be used to monitor the gas stream after the first sorbent bed and to inventory the gases stored for use in the resistojets. Magnetic type spectrometers are electrically simpler and more reliable than quadropole or time-of-flight instruments. (A small magnetic type mass spectrometer was successfully flown on Pioneer-Venus.)

The instrument will be housed within the USL for each maintenance and for access to the instrument. For example, it will be required periodically to have filament in the ion source replaced. This simple procedure would be very difficult to perform on EVA if the instrument were mounted on the Gas Waste Management module in the vacuum of space.

The vacuum requirements for the mass spectrometer will be provided by appropriate tubulation to the vacuum of space. This procedure then removes the necessity for vacuum pumps and getters usually required for mass spectrometer operations. Only trivial quantities of gas will be vented to space during any mass analysis. Use of the space vacuum serves not only to reduce the weight of the instrument but also reduces the power requirements. It is expected that the instrument will weigh less than 12 lbm, have a volume of less than 0.5 ft^3, and require power somewhat less than 7 watts.

The single instrument will be used to monitor the gas stream periodically and to inventory the gases in the storage tank as required. The latter need occur only be two or three times in a 14 day period.

7.9.4 Liquid Vapor Separator

Some experiments, such as the continuous flow electrophoresis, require bubble-free liquids for successful separations of materials that are suspended in the liquid. Such experiments, therefore, require liquids that are free of dissolved gases to prevent bubble formation.

Commercially available separators are designed to remove relatively small amounts of liquid from a gas. Hamilton Standard specially designed liquid-from-gas separator is used in the TIMES unit, and Hamilton Standard is considering a design modification of their design to yield gas-from-liquid separation.

Less critical requirements (than the electrophoresis experiment) can use a liquid vapor separator derived from the TIMES unit. The more critical requirements will require a membrane type degasser such as that used for the electrophoresis experiments on Shuttle. It provided maximum air removal from water. It is a good candidate for further development. It has no moving parts; the water is flowed through the membrane system and the dissolved air passes through the pores of the membrane while the water is retained in the flow. It had a short life on the Shuttle and had to be replaced while on orbit during a nine day mission. This was most probably due to pore clogging by a protein gel caused by the protein becoming denatured by the degassing process. To increase the life of the system the protein can be intentionally denatured and filtered at the experiment prior to submitting the water to the degasser system.

7.9.5 Alcohol Removal

One of the concerns in the Water Waste Management System is the removal of alcohol from the water. The well-known Iodoform reaction[19] can be used to remove certain alcohols such as ethanol and isopropyl alcohol. For example, with ethanol the reaction is where the iodoform can be removed by filtration and the sodium salt can be removed by ion exchanged to yield water. Ethanol is the only primary alcohol which reacts in this manner. Methanol (a primary alcohol) does not react. Ketones, such as acetone and methyl ethyl ketone (MEK) also react. It should be noted that the reaction goes to completion, i.e., all of the alcohol reacts.

If the driver for alcohol removal is the concern with azeotrope formation then experimenters could be encouraged to use methanol since it does not form an azeotrope with water. If the concern for alcohol removal is not azeotrope formation, then experimenters should be encouraged to use ethanol or isopropyl alcohol (IPA) since their removal can be readily accomplished.

There is another method which presumably can remove alcohol from water. This is a treated silica, commercially known as silicalite, which acts as a sorbent for alcohol. However, it removes only a few milligrams of alcohol per gram of silicalite. This would require considerable logistics support of resupply and return to Earth of expended silicalite. It is probably a much less desirable method than the iodoform reaction.

7.9.6 Vacuum Pumps and Compressors

The compressor for storing the effluents prior to resistojet venting will be required to operate outside of the USL in the vacuum of space, which places a severe restriction on the design of the compressor. Discussions with vendors indicate that without specialized precautions leakage to vacuum may be expected. The membrane-type compressor assures contamination free compression whereas with the piston type the potential exists for contamination from the lubricants used in the system. With either type the movement of parts in the compressor is such that "g-jitter" may become excessive. Oilless vacuum pumps are being developed by Edward High Vacuum Corporation (Colorado) and Varian Associates (Palo Alto) to support the semiconductor industry and could be used for this Space Station application.

The Davies Aerospace Corporation has investigated various oilless positive displacement compressor configurations. Discussions with the Davies Aerospace chief engineer, Mark Bass, indicate that the design and development of a reliable compressor would require 2 years. A likely candidate for future development would be a low speed, electrically driven membrane type compressor. Concepts required to meet pressures ranging from 100 to 300 psia and compressing the inert gases specified in the waste fluids inventory would require less development time than the compressors required to meet the constringent requirements of the propulsion system. However, the compressors developed for the O_2/H_2 systems would be adequate for IWFS application assuming the corrosive effluents were removed in the waste gas cleaning process. Power requirements were examined for storage pressures ranging from 300 to 1000 psia and are presented in Table 7.8-2 along with tank volume requirements.

7.9.7 Line Sizing

The line sizing is based upon the assumption of evacuation of an experiment module, containing (1 m^3) of gas, to a pressure of 2 x 10^{-5} psia (10^{-3} torr) in half an hour. It is estimated that a 1-1/2 in tube is required from the experimental module to the vacuum pump which exchausts the module. The rest of the Gas Waste Management System can be plumbed with 3/8" tubing.

7.9.9 Waste Storage and Tank Change-Out

A number of options are available for the storage of waste and for change-out of the waste storage tanks. Waste can be stored in "standard" zero-gravity tanks such as bladder tanks or bellows tanks. Bladder tanks may be more desirable for the storage of wastes because they are more easily cleaned (or the bladder can be replaced) and bladder materials can be selected which are compatible with the specific uses. Quick disconnects are typically provided to allow easy change-out of the tanks.

An additional concept is double-walled bladders for the storage of waste liquids in the racks. These bladders, similar to typical blood bags used by the Red Cross and other medical organizations, are inexpensive and very rugged. When filled, the bladders could be removed and stored in a liquid-tight locker for return to Earth. The bladders would have standard QD's for ease of change-out. The advantage of this concept is the reduced return weight compared to typical storage tanks.

Storage of waste gases can be accommodated by composite pressure vessels. Although there are potential problems for composite materials in terms of life, they do reduce the return weight for the logistics module, and can be replaced often if necessary.

7.10 OPTIMIZED INTEGRATED WASTE FLUID MANAGEMENT CONFIGURATION

The recommended baseline for the Integrated Waste Fluid System (IWFS) is shown in Figure 7.10-1. A typical experiment rack, as shown in the upper left of the figure, will have three basic fluid interfaces with the IFWS: a waste liquid collection interface, a waste gas collection interface, and a vent system interface. Particulate filters are provided on the experiment side of these interfaces to protect the IWFS and its downstream components. Waste gases and liquids are removed from the experiment boxes via the respective waste collection systems. The vent line interface is provided both for emergency venting and for evacuation of the experiments to space vacuum.

The Waste Gas Collection system collects the waste gases from the experiments via two vacuum pumps in parallel. It is anticipated that small amounts of liquid may be collected in this system. Additional heat, for example, waste heat from the catalytic converter, may be required to keep these

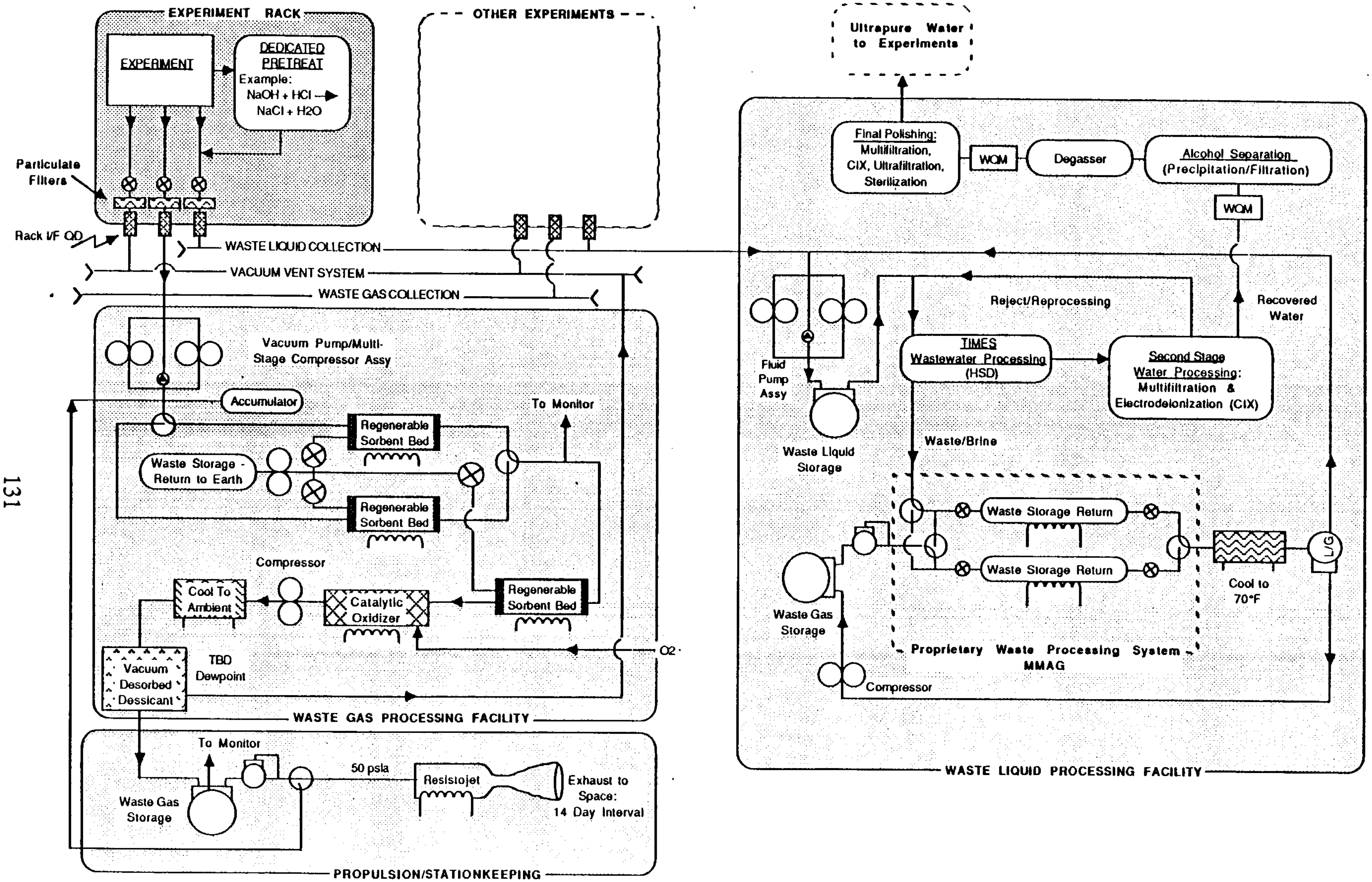

Figure 7.10-1 Recommended Configuration for the Integrated Waste Fluid System

substances in the gas phase. An accumulator is provided to accommodate transients in the flowrate through the processing system, to accommodate variations in the flow from experiments, and to accommodate gases from the downstream storage tank which may need recycling.

Regenerable sorbent beds are used to remove most of the organic contaminants in the gas streams. Two of these beds are located in parallel to allow desorption of open bed as the other is adsorbing. Desorption is accomplished via a combination of reduced pressure and increased temperature. Initiation of the adsorb/desorb cycles is based on timing, with a monitor used to check for breakthrough of the beds. A third sorbent bed is located downstream of the first two beds as a precaution in the event of bed breakthrough.

After passing through the sorbent beds, the gas is passed through a catalytic oxidizer to remove any remaining contaminants which have not been captured by the sorbent beds. Typical catalysts for this type of application include Hopcalite and other palladium on alumina catalysts operating at 200° to 800°F. The catalytic oxidizer may not be required, depending on the effectiveness of contaminant removed from the gas stream.

A compressor, downstream of the catalytic oxidizer, raises the pressure of the gas to the required storage pressure. The gases are then cooled and passed through a desiccant to reduce the dewpoint to a temperature compatible with transfer to resistojets external to the station. The desiccant is sized to require vacuum desorption only during periods when the external contamination requirements will not be violated.

The gases are stored in a storage tank where a final analysis is performed to insure compatibility of the gases with the resistojet and to calculate resistojet performance. If the gases fail these analyses, they are transferred via the three-way valve back to the accumulator at the inlet of the processing system.

The waste liquid system performs the function of recovering usable water from the waste liquid stream and minimizing wastes for return to earth. A fluid pump assembly is used to collect the liquids from the experiments. A protocol will be established to preclude combining potentially incompatible liquids. The liquids are stored in a waste liquid storage tank, probably of the metal bellows variety, for flow normalization. The wastes then continue to the TIMES (Thermoelectric Integrated Membrane Evaporation Subsystem). The water recovered by the TIMES is further processed in a second-stage process using a combination of Multifiltration and Electrodeionization (or continuous ion exchange, CIX.[21]). Reject from this second stage processing is recycled back to the TIMES.

A water quality monitor analysis is performed to the recovered water to verify its purity. The product water then enters an alcohol separation process. This process uses the well-known iodoform reaction illustrated in Figure 7.10-2 [19]. The products of this reaction are removed by a combination of ion exchange and filtration.

Following the alcohol removal process, the product water is degassed using a silicone membrane degassing technique[21] and then once again analyzed for purity. At this time, it is anticipated that conductivity will be the primary monitoring technique used.

A final polishing, consisting of multifiltration, CIX, ultrafiltration, and sterilization, will be performed. Sterilization can be accomplished by use of UV radiation or thermal cycling to 250°F. The final product water will be acceptable for use in experiments.

The reject, or brine, from the TIMES processor will be further treated in a Martin Marietta proprietary process which incorporates a phase change of the liquid. The effluent is cooled to 70°F, which condenses the water, but leaves the Freons™ in a gas phase with any other

ETHANOL + NaOI $\longrightarrow$ RCOO⁻ Na⁺ + CHI3 (iodoform)

Removed by Ion Exchange Resin (RCOO⁻ Na⁺)

Yellow Precipitate (Melting Point 246°C) Removed by Filtration (CHI3)

- **This reaction also works with isopropal alcohol (IPA). Recommend substituting IPA for methanol.**
- **Other primary alcohols (i.e., methanol) do not react in this manner.**
- **This reaction will also remove ketones such as acetone and methyl-ethyl ketone (MEK).**
- **Note that the reaction goes to completion, thus removing all the alcohol.**

Figure 7.10-2 Iodoform Reaction for Alcohol Removal

non-condensable gases. The water is collected with a phase separator and returned to the TIMES processor. The Freon™ and other gases are compressed and stored in a pressure vessel for intermediate storage and then released into the waste storage tanks containing the solid waste for return to Earth.

7.11 OTHER CONSIDERATIONS

This section describes some concerns and questions that arose during the study and did not seem to fit in the topics discussed above. One of these questions requires more information on the method of cleaning surfaces in the various facilities and, in a related fashion, the mechanism for etching surfaces. Both of these techniques require placing a fluid on a particular surface, moving the chemical on the surface, and containing the liquid. How this will be accomplished has not been defined.

A second undefined area is photography. It is not clear whether these are x-ray powder patterns or photographs through a microscope. The facility requiring developer and fixer will probably have to store these materials because of these extensive list of involved.

Since the vacuum vent system can impart an acceleration when operated, and since the waste fluid systems will have moving parts, there is a specific time period when these systems can and cannot be operated; a venting schedule must be defined. The pressure limit of 5×10^{-3} psia (0.25 torr) prior to vacuum venting does not seem to have any particular justification. This requirement may or may not be sufficient or overly constringent and should be reevaluated.

The final concern is over the usefulness of many of the analytical methods. For example, much of the analysis and associated equipment related to the crystal growth experiments is necessary only if the results are to be used in real time to modify experimental parameters or if the crystals will be damaged by return to Earth. It is expected that the crystal growth tests will involve a matrix of parameters (heating rate, cooling rate, starting and ending temperatures, etc.) that will not depend on the previous parameters to determine the next set. Since it may take as long as eight weeks to run one crystal growth experiment, return of the grown crystals to Earth for analysis may save a great deal of equipment weight, etc. This may eliminate the need for the cutting and polishing facility and many concerns over toxic particulates. Finally, this will eliminate the need for extensive technical training for the astronauts.

7.12 INTEGRATED WASTE FLUID SYSTEM CONCLUSIONS AND RECOMMENDATIONS

The integrated waste fluid system is a major design driver of the performance of the Space Station. The operational flexibility of the IWFS will directly effect the operational efficiencies associated with on-orbit experimentation and the use of crew time. The recommended approach discussed in Section 7.10 of this report provides a feasible, safe method for waste disposal that provides for future growth and international integration. A major design concern with the recommended approach is the required development of on-orbit, long life compressors. Although the development associated with an on-orbit compressor would be extensive, it is not a surmountable problem and potential electrically motor driven, low speed, positive displacement type compressors are being investigated by industrial contractors.

To adequately size and verify the recommended integrated waste fluid system concept, all constituents including acid and base concentrations, cleaning solutions, monomers, and etching solutions must be adequately defined. Procedures for each experiment also need to be defined. After a revised waste fluid system inventory is established, individual effluents should be examined for hazardous conditions, and cross reactions between effluents should be examined for special reactions and long exposure times. Experimenters requesting the use of hazardous fluids or fluids that are incompatible with the IWFS should be responsible for their the isolation, containment, and disposal.

Vacuum venting concepts proposed in the Martin Marietta and Boeing Concepts result in the backflow of vented gases to the Space Station as the gas moves from a transition flow to a free molecular flow. Using vacuum pumps to bring the experiments to a condition of 0.001 torr would allow for emergency venting only and preclude problems associated with the control and monitoring of the vacuum vent line and of the release of particles that may interfere with external experiment viewing.

In conclusion, the verification of an operationally efficient integrated waste fluid system will require a continual exchange of information between the USL and international experimenters, the NASA Lewis resistojet developers, the station operations and enviromental working groups, and the Work Package contractors.

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8.0 INTEGRATED FLUID SYSTEM ASSESSMENT CONCLUSIONS AND RECOMMENDATIONS

The most important conclusion reached during the Integrated Fluid System Assessment was that there are significant benefits to be gained by integrating the Space Station fluid systems beyond their present configurations. These benefits include life cycle cost reductions and increased reliability through the use of common hardware within each of the systems and throughout the Space Station as a whole. The integration of these systems should propel the individual work package designs toward greater Space Station operational efficiency. However, time is critical, and fluid system requirements and fluid inventory data must be revised before the designs are set. A major effort should be focused on obtaining the necessary fluid information needed to support a cooperative design effort among individual work packages and fluid systems integrators.

An excellent example of the benefits gained through component commonality was discovered during the integrated oxygen /hydrogen system assessment. Reducing the number of electrolysis units from 8 to 4 and reducing the supporting equipment to perform the same functions resulted in a 10 year cost savings of $142 M, or 20%, over the present configuration.

An investigation of the supply, distribution and storage gas configurations showed that nearly all the gases could be supplied in common tanks with the same lines, valves and associated hardware used to construct the different systems. The major benefit of using the same hardware is a reduction in the number of spare parts required to be stored at the station which would otherwise take up valuable space. The use of identical parts correlates to reductions in hardware development, qualification and test, launch, and overall life cycle costs.

Present configurations do not focus on the implementation of common hardware. For instance, liquid storage tanks are all being assessed individually. Different tanks are being recommended for the propulsion water system, the environmental control and life support system and the liquid nitrogen system. A common tank should be investigated to support all of these requirements, potentially a tank that provides liquid acquisition through capillary screens or vane devices. A tank that meets the constraining requirements of providing pyrogen free, potable water to the experiments and is capable of supplying liquid effluents in the future. At a minimum, the same tank should be used for storage of propulsion water and Environmental Control and Life Support System water. Research and developmental testing should begin now to provide that one tank that could meet all the necessary requirements for liquid storage on the station and could support the fluid servicing facilities in the future.

Investigation of the fluid systems and associated requirements revealed a delicate balance between individual fluid systems across work packages and a strong interdependence between all other fluid systems. Table 8.1-1 presents the parameters that are highly sensitive to changing Space Station requirements and the fluid systems that these parameters affect. A change form the initial food water content of 1.1 to 2.68 lbm/person/day would increase the water available for propulsion by 98%. Or, in the event that resistojets are unable to vent the CO_2/CH_4 mixture, the ECLSS may be driven to a Bosch or advanced Sabatier CO_2 reduction process to avoid large logistics requirements for deorbiting the waste effluents. This type of interdependency requires close coordination among USL and international experimenters, individual Work Package contractors, Attached Payload experimenters, resistojet developers, and operational working groups, including those associated with contamination, power, and microgravity requirements.

Table 8.1-1 Fluid System Interdependency with the Space Station Design

SYSTEM	SENSITIVE PARAMETERS	EFFECT ON SPACE STATION DESIGN
INTEGRATED OXYGEN/ HYDROGEN SYSTEM (ECLSS AND PROPULSION)	• FOOD WATER CONTENT • CO2 REDUCTION PROCESS • RESISTOJET CAPABILITY	**IWFS** - DESIGN OF FLUID CONDITIONING COMPONENTSRESUPPLY **PROPULSION** - O2/H2 STORAGE TANKS REQUIRED FOR STATION KEEPING ADDITIONAL H2 OR CO2/CH4 MIXTURE AVAILABLE FOR IMPULSE **SHUTTLE** - RESUPPLY SCENARIO/ INTERFACE DESIGN **LOG** - VOLUME REQUIRED FOR RESUPPLY **USL** - WATER AVAILABE FOR EXPERIMENTS **IWS** - STORAGE CAPACITY/ DESIGN CONTINGENCIES
INTEGRATED NITROGEN SYSTEM (INS)	• EXPERIMENT REQUIREMENTS • SCARRING REQUIREMENTS FOR MMU, OMV AND SERVICING FACILITY • THERMAL ENVIRONMENTS	**LOG** - LOGISTICS RESUPPLY VOLUME **INS** - NITROGEN STORAGE AS LIQUID OR GAS **MMU** - EVA/IVA DESIGN REQUIREMENTS FOR MAINTENANCE **INS** - TANK DESIGN **INS** - SCARRING FOR GROWTH
GASEOUS RESUPPLY DISTRIBUTION SYSTEMS	• EXPERIMENT REQUIREMENTS	**LOG** - VOLUME REQUIRED FOR RESUPPLY **LOG** - NUMBER OF SPARE PARTS **MMU** - EVA/IVA MAINTENANCE PROCEDURES/ DESIGN REQUIREMENTS
INTEGRATED WATER SYSTEM (IWS)	• PROPULSION REQUIREMENTS • FOOD WATER CONTENT • CO2 REDUCTION PROCESS	**IWS** - LOCATION OF WATER STORAGE **LOG** - VOLUME REQUIRED FOR LOGISTICS RESUPPLY **SHUTTLE** - SHUTTLE RESUPPLY SCENARIO **INS** - VOLUME REQUIRED IN NITROGEN TANKS **IWS** - TANK/FLUID SYSTEM COMPONENTS
INTEGRATED WASTE FLUID SYSTEM (IWFS)	• VACUUM VENT CAPABILITY • RESISTOJET USE OF CH4/CO2 MIXTURE • INSUFFICIENT FLUIDS INVENTORY INFORMATION	**ECLSS** - USE OF SABATIER SYSTEM **ECLSS** - USE OF H2 FROM BOSCH SYSTEM **PROPULSION** - PROPULSION RQMTS/ SIZING FOR WATER STORAGE **IWFS** - SIZING FOR WASTE GASES **IWFS** - DESIGN OF COMPONENTS FOR WASTE CONDITIONING **IWFS** - INSTRUMENTATION FOR SAFETY AND INVENTORY **IWFS** - COMPRESSOR DESIGN **JEM** - FLUID CONDITIONING DESIGN PRIOR TO USE OF THE IWFS **COLUMBUS** - FLUID CONDITION DESIGN PRIOR TO USE OF THE IWFS **ATTACHED PAYLOADS** - EXPERIMENT SCENARIO FOR VIEWING/ VENTING CONSTRICTIONS

APPENDIX A

Water Quality Monitoring

The primary responsibility of water quality monitoring lies with the ECLSS, and in specific, with the Water Recovery and Management (WRM) function of the ECLSS. However, in an integrated system, there is a system responsibility to insure that contamination of the potable water does not occur through the integrated system's interfaces, nor through the integrated system itself. This implies the requirement for a water quality monitoring function within the integrated water system itself.

It is assumed that a water processing failures or anomalies will occur during the life of the station. In, this event, decontamination procedured will be followed to restore the system. Water quality monitoring requirements must address the capability to verify water quality after decontamination has been completed.

Since contamination from various interfaces can create safety problems for the station crew, the recommended approach is to verify water quality on both sides of an interface before a transfer of water is made. For example, before water is transferred from the Orbiter to the common water distribution lines in the station, the quality of the water on both the station side and Orbiter side of the interface would be verified.

Although the quality of the water introduced to the integrated water system will be controlled, it is still important to monitor the water quality on a periodic basis. One important reason for this monitoring is the potential for microbial contamination.

The potential for microbiological contamination of potable water has been raised as an issue throughout the Space Station Phase B effort. Although not all the contamination sources and mechanisms have been thoroughly defined and understood, the potential for contamination has been documented in a great number of ground based applications, as well as with prototype space-type water processing hardware. More than chemical contamination, microbial control is a critical issue in water distribution system design since its initial occurence may be undetected, and the magnitude of the problem can grow without further contamination from an external source.

The water quality monitoring requirements for the integrated water system may be impacted by the water processing technologies selected for the station, as well as the water quality monitoring technologies selected for the ECLSS and PMMS.

Monitoring Philosophy

Two philosophial issues are of concern in selecting water quality monitoring concepts for the integrated water system. The first is direct monitoring versus surrogate monitoring. Direct monitoring requires the measurement of the parameter in question. Surrogate monitoring utilizes the measurement of a parameter in some way related to the one in question. The use of a surrogate parameter involves the development of a correlation factor between the parameter in question and the surrogate parameter. Since many variables may be involved, development of the correlation may be a long and difficult (expensive) process, if it can be accomplished at all. Typically, direct monitoring is preferred since no correlation must be developed.

A second overall water monitoring philosophy involves batch vs. continuous monitoring. The requirement for batch versus continuous monitoring is based on several issues including monitor/sensor response time, bacteria monitoring requirements and techniques, operational considerations, the system architecture, and implementation of process monitoring (surrogate monitoring of the water recovery processors to indicate product water meets water quality requirements) versus on-orbit water quality verification (verification that all individual water quality specs are met).

If the required monitoring inherently has a long response time, then it may be necessary to perform the monitoring function on a batch basis. For example, if bacteria cultures are required on all product water, then batch monitoring will be required. Monitoring of specific contaminants at low concentrations may require the use of monitoring techniques, such as GC/MS, which have inherently slow response times necessitating batch monitoring.

If a process monitoring philosophy can be adopted and the selected water recovery processes monitored with relatively rapid response instrumentation, such as pH and conductivity, then batch processing will not be required. However, if biological or chemical verification of all product water is required, the monitoring requirements will drive us to batch monitoring.

The NASA specifications for water quality include a broad spectrum of parameters, both chemical and biological. The capability to measure all these parameters is difficult and expensive to accomplish on the ground, and requires extensive laboratory facilities and equipment. It is commonly recognized that such a capability cannot be provided in an orbiting space platform with existing technology. Therefore, it is anticipated that both direct and surrogate as well as batch and continuous monitoring will be implemented for water quality monitoring on Space Station.

Microbiological Monitoring

The greatest water quality monitoring issue seems to center on the requirements for microbiological monitoring.

The requirement for microbial verification of all product water prior to use may have a major impact on system design, requiring development of on-orbit automated microbiological monitoring or severely impacting crew time allocation for such monitoring activities. Depending on the specificity of the microbial assessment, the system must be designed for up to 48-hour holding of processed water during which cultures are allowed to incubate. This has a significant impact on weight and volume for the quantities of water anticipated. The real problem comes from the requirement to have available water in the event of a failed batch of water, since the failed water must be reprocessed and reverified- a process which would take an additional 48 to 72 hours. This problem could be alleviated if a real time bacteria monitor could be developed. However, development is expected to be costly, and such a monitoring system would not be available at PMC.

Certification of a process to adequately control microbial presence or growth would make periodic monitoring feasible. Periodic monitoring, at 45 or 90-day intervals, could be either ground based or performed on orbit. Ground based testing would require proper protocol for ensuring a viable water sample reaches the laboratory, but would relieve the crew of the monitoring responsibility and eliminate the cost for an expensive development program for a flight qualified monitoring system.

At this time, certification of microbial control does not appear to be a viable, acceptable approach, based primarily on the lack of knowlege of the station microbiology, and the inherent crew risk.

For the integrated water system water quality monitoring applications, an approach can be applied which will meet the stated requirements, minimize the cost and development risk, and still provide maximum crew safety.

Water quality is first checked at the integrated system interface prior to transfer of water. This is accomplished by the water quality monitoring system for the ECLSS and PMMS in the case of their interfaces. Water delivered by the PLC could be analysed on the ground prior to launch, with several parameters rechecked by the integrated water system monitor before being transferred to the station. The integrated water system could also be used to verify several parameters such as iodine concentration and conductivity, prior to transfer to the station. Microbial quality of the station water supply could be determined by a separate microbial assessment performed batch mode on a tank-by-tank basis. Additional selected chemical analyses, which cannot be performed readily in a real-time on-line mode, can also be performed in parallel with the microbial assessment. The water can be used once these batch assessments are completed with positive results.

To supplement this standard analysis of the water quality, more detailed chemical analyses can be performed periodically both on orbit and on the ground. These assessments are performed to look at long term trends of contaminants which occur in very low concentrations, and need not be monitored in each batch of water. The ground based monitoring can perform analyses which require analytical resources and techniques not available or appropriate to provide on-orbit. The on-orbit analytical capabilities can be utilized to verify systems after decontamination procedures have been implemented and completed.

A preliminary definition of the specific parameters to be monitored by the integrated water system can be selected based on the following rationale:

1) Surrogate indicators - on-line measurement of parameters which are general indicators of overall water quality and biocide content (e. g. conductivity and iodine, respectively).

2) Process failure indicators - parameters which will change when a failure of some component of a water processing system fails. These can be determined by a failure modes and effects analysis (FMEA).

3) Crew health hazards (acute) identified in materials lists - contaminants identified in an integrated station material list which pose potential acute health risks to the crew.

4) Low level (trace) toxic contaminants which are identified by NASA specifications.

Based on the above discussions, it is recommended that the integrated water system provide a water quality monitoring system which includes as a minimum the following capabilities.

Iodine - The baseline biocide for the space station water systems is iodine. In order to ensure that microbiological growth is controlled, a specific minimum iodine concentration must be maintained. A monitor must be provided to ensure that this minimum concentration limit is observed.

Total Organic Carbon (TOC) - The TOC measurement is a measure of the performance of the water processors in the ECLSS, and is necessary to ensure that specific contaminant concentrations, such as those for alcohols, are met. However, a flight TOC monitor is considered highly developmental.

Conductivity - This is a general water quality parameter which is easily accomplished, and provides a measure of overall ionic quality of the water.

Microbiological Monitoring - This is required to ensure that the water is safe for human consumption.

A discussion of potential water quality monitoring techniques follows:

Total Organic Carbon

Total organic carbon consists of all non-carbonate carbon in the water sample to be tested. Several methods that determine TOC exist and have been incorporated insto automated devices. Most of them invlolve the oxidation of organic carbon to CO_2 followed by measurement of the $C0_2$ produced.

UV PROMOTED OXIDATION--IR DETECTION-- In this method sample water is acidified with phosphoric acid to drive out all ambient carbonate. The carbonate free sample is than illuminated with UV light that oxidizes all organic carbon to CO_2. The CO_2 gas produced passes through a porous membrane into an infrared analyzer where its quantity is measured.

UV & O_2 PROMOTED OXIDATION--CONDUCTIVITY DETECTION--This technique measures the conductivity of a sample before and after sample oxidation. Any increase in conductivity is assumed to be due to carbonate produced by oxidized organics, and the increase in conductivity is used as a measure of Total Organic Content.

PERSULFATE OXIDATION/IR DETECTION--Sample water is acidified to drive off ambient carbon after which persulfate is added to oxidize all organic carbon to CO_2. CO_2 produced is then measured by an infrared detector, and is used to determine TOC.

UV PROMOTED OXIDATION/CONDUCTIVITY DETECTION-- The conductivity of the sample is measured both before and after the sample is illuminated with UV light. The change in sample conductivity is used as a measure of organic carbon oxidized by the UV light and TOC.

UV ABSORBTION-- This method uses a sample's UV absorbance to determine its total organic content. The UV absorbtion of a sample has been empirically related to its TOC level, and this relation, along with its UV absorbtivity is used to determine a sample's Total Organic Content.

IODINE-- Elemental iodine, (I_2), has been recomended as the baselene biocide candidate for Space Station potable water. The iodine is added to the water through the use of an iodinated resin. Such a resin, termed a microbial check valve (MCV), is presently used on the Orbiter. In order to ensure that the MCV is functioning properly, it will be neccesary to monitor the iodine content of the water.

IODIDE (I-)-- Concentration is indirectly related to I_2 concentration, and two methods for monitoring I_2 by monitoring I- were considered. These methods were Ion Selective Electrodes and Ion Exchange Chromatography. However, since neither of these methods can monitor I_2 concentration with the sensitivity required by NASA, they were not evaluated in the trade study.

OXIDATION/UV ABSORBTION-- This technique measures iodine content by oxidizing aqueous iodine to hypoiodous acid (IO-) and measuring its absorbance at a wavelength of 290 nanometers.

OXIDATION/COLORIMETRY-- In this technique, the sample is mixed with a reagent containing an oxidant and leuco-crystal dye to form a colored species whose absorbance is directly related to the sample's I_2 content.

Microbiologhical Monitoring

The requirement for microbiological content of space station water is, for the purposes of this report, assumed not to exceed 1 colony forming unit (CFU)/150 ml. A CFU is defined to be any life form capable of living in nutrient broth in open air.

Several techniques for monitoring microbial life are presented as follows. Many were part of automated systems, such as the TURBIDITY/DILUTION TO EXTINCTION method, or were compact like the LASER EXCITED FLUORESCENCE and LUCIFERASE/ATP BIOLUMINESCENCE methods. None of these methods came within the required sensitivity by a factor of 100.

MEMBANE FILTRATION MICROSCOPY-- This was the only method that could meet the requirement of 1 colony forming unit/150 ml. In this method, two liters of sample water are filtered through pads designed to trap all particles larger than .25 microns. After filtration, the pads are soaked in a nutrient-indicator broth without disturbing the surface on which any microbes might be resting. Any viable life living on the surface of the pad will consume nutrients soaking through to the surface of the pad and will produce organic acids as waste products. These acids will cause the indicator in the broth to change color and form a halos around the viable microbial life forms. After an incubation that permits the microbes to grow their halos, the pad is transfered to a microscopic stage where it will be scanned by a television/particle counter. The particle counter will count the number of halos on the pad and use this count to determine the waters microbial content.

A number of considerations must be made in the selection of monitoring technologies. This section will present some of these considerations, and discuss them with respect to application on Space Station.

Performance Sensitivity Standards -

The performance of the monitoring system must reflect the limits imposed in the water quality specifications. As of this time, these requirements have not been firmly established, and can be expected to evolve with the station and payload/experiment design.

The dissimilar nature of microbial and chemical contaminants leads to separate procedures for the assessment of each. The need for high sensitivity in measuring contaminants dictates that batch testing be an integral portion of the monitoring scheme. This is contrary to the requirement that contaminant monitoring be in real time, however it cannot be avoided due to technological limitations.

System Evolution /Growth Capability -

The performance standards have not been completely defined, making the configuration of the monitoring system subject to further refinement at a later time. The hardware requirements for the water quality monitoring system are subject to change as the performance standards and specifications evolve.

Maintainability -

The issues associated with maintenance operations involve resource drain (crew time, materials, and waste disposal), process failure indicators, failure modes and consequences, fault detection, and repair activities. Construction of the monitoring system in individual test modules (a single analytical test with standard sample ports and data interface hardware) would minimize crew involvement with maintenance operations. Computer generated diagnostic tests would allow the detection of a faulty test module and direct the corrective actions to insure proper functioning of the monitoring system as a whole.

Commonality with Other Systems -

The measurements required by the integrated water system water quality monitor will be similar, or in some cases identical, to those required by other station subsystems such as ECLSS, PMMS, and the HMF. An integrated development program, cosponsored by the responsible centers and contractors, would reduce the development costs and improve hardware commonality - both goals of the space station program.

Automation and Robotics -

There are many potential applications for automation and robotics (A&R) in the water quality monitor subsystem. These areas include fault diagnostics, trend analysis, and microbiological monitoring. This latter area holds high potential for the use of robotics in the preparation and manipulation of samples, and for automation by a computer driven microscope for counting bacterial colonies. This combination would allow automatic determination of the number of colony forming units (CFU) in a test volume of water.

Technology Selection & Monitoring Application Recommendations

A preliminary set of parameters to be monitored by the integrated water system is provided above. It should be noted that specific monitoring technology selections are predicated on an overall water quality monitoring philosophy, as well as water recovery technology selections, and the station atmospheric contaminants. The selections are also sensitive to the monitoring requirements, i.e. the levels of detection. Changes in these levels of detection can have marked impact on the technologies selected. Therefore the selection of monitoring technologies is considered beyond the scope of this effort.

Program Recommendations

Water quality monitoring requirements will evolve as selection and characterization of water processing technology continues, and as user requirements/impacts are defined. Integrated ECLSS testing at MSFC, the ECLSS Technology Demonstrator Program, Phase C/D ECLSS hardware development and qualification programs, and ground-based development and certification of experiments/payloads will all contribute to this evolution of requirements.

Since the specific monitoring requirements will not be known until later in the program, it is imperitive to implement a rigorous monitoring capability development program to ensure that eventual program needs will be met.

It is not possible to identify all contaminants which may occur in the station environment. It will be important to provide the station with a flexible, broad-based characterization capability to be used on a periodic basis, or in the event of a spill, anomoly, or accident. This need not be an on-line monitor, as long as the ability to manually sample the water system and deliver the samples to the analyzer is provided. A complete on-orbit analysis capability is not required, but the capability to transmit raw data to earth for analysis must be provided.

Water quality monitoring is presently a major concern in the Space Station Program, since the water quality specs and monitoring requirements have not been firmly defined. In addition, the NASA-funded development work presently in progress does not appear to address all the potential monitoring issues (e.g. microbial monitoring). Monitoring efforts are required in the following areas:

1) Routine Analysis
   - Chemical (partial listing)
     - TOC
     - Specific Toxicants (e.g. halocarbons, phenols)
     - Heavy Metals
     - Residual Halogen
     - Ammonia
   - Microbial
     - Various Bacteria
     - Viruses
     - Molds and Yeasts
2) Anomaly/Emergency Analysis
   - Chemical - TBD
   - Microbial - TBD

3) Ground-Based Water Quality Analysis
   - Chemical - TBD
   - Microbial - TBD

APPENDIX B

Water Decontamination Methods

There are two types of contaminants that are of Concern within an integrated water system: Chemical and Microbial. Lists of possible methods for both are presented below.

<u>Chemical Decontamination</u>

Option (1) Jumper/Reprocess

This option provides a jumper assembly (OSE) used to connect the processed water distribution lines to the waste water collection lines to allow the contaminated water to be reprocessed by the normal processing equipment.

This approach has several strong points. It requires a minimum of orbital support equipment (essentially a jumper line and possibly a pump), and requires only a small number of quick disconnects or maintenance disconnects in the installed system. The power requirement for this option is also very low.

The effectiveness of this option is somewhat questionable. If the contamination problem was caused by a processor failure, then there is a high probability that this recovery process will be effective. However, if the contamination is caused by the inability of the processor to remove the contaminant, then reprocessing will not resolve the problem.

This option has an additional problem in that the available tankage on the waste collection side of the system may not be adequate to transfer all the contaminated water at one time, requiring several flushes to the waste collection tank to effect complete recovery. Another piece of orbital support equipment, a tank, could be provided to eliminate this problem.

Water quality analysis to verify the recovery process effectiveness on orbit is required.

Option (2) Jumper/Sorbent Bed

This option utilizes a jumper system to flush the system and process the contaminated water through a disposable sorbent bed. Both the jumper assembly and sorbent bed are OSE.

This approach also has several strong points. It requires only slightly more orbital support equipment than option (1) (essentially a jumper line, a pump, and sorbent bed), and again requires only a small number of quick disconnects or maintenance disconnects in the installed system. The power requirement for this option is also very low.

The potential effectiveness of this approach is greater than for option (1) since the sorbent selection and sizing of the beds can provide a capability beyond the normal processing equipment. In addition, this approach would also allow reprocessing through the normal processors. This approach does not have the problem of potential waste tankage undercapacity.

Water quality analysis to verify the recovery process effectiveness on orbit is required.

Option (3) Flush/Store/Return

This option simply flushes the contaminated water into a waste storage tank for return to earth. This option requires both the jumper assembly and a number of waste tanks with the associated weight and volume impacts.

One advantage of this approach is the high potential of effectiveness. The effectiveness is high due to the fact that there is no attempt made to recover the contaminated water. Power is again very low.

Since the water is not recovered, replacement water must be on board to replace the contaminated water, resulting in a high weight and volume impact.

<u>Microbial Decontamination</u>

Option (A) Flush with Oxone

This option utilizes a jumper to recirculate the contaminated water, and adds oxone for microbial decontamination. Mechanical action for removing biofilm is provided from turbulent flow induced in the piping. The contaminated water is then treated via option (1), (2), or (3) above.

There is a safety issue with this option related to the toxicity and handling of oxone. A mixing divice must also be provided to dissolve the solid oxone in the water. Oxone may damage system piping and component if used in high concentrations or for extended periods of time.

Microbial analysis after recovery is required to verify proper water quality.

Option (B) Steam lines

A process for steaming the piping requires storage tanks for the displaced fluid, and a steam generator as OSE.

Steam cleaning is a very effective means of controlling microbial contamination, however this option requires draining/filling lines on orbit, which is a complicated process to perform on-orbit in zero-G. It also imposes a a number of safety risks. A means must be provided for dealing with the contaminated steam, and the high temperature steam is an inherent risk. This option is also has a relatively high power demand.

Microbial analysis after recovery is required to verify proper water quality.

Option (C) Flush with hot water

This option requires pump, jumper, and heater assembly to circulate and heat the the water in the piping. The heat kills the microorganisms, and turbulence from the flow provides the mechanism for biofilm removal.

This technique is considered very effective in controlling microorganisms. It is also relatively safe, since there is no need to handle toxic substances. There is some degree of risk involved due to the high temperature and pressure of the water circulated in the piping. There is also a fairly high power demand. Following the heating cycle, the water can be processed via options (1), (2), or (3) above, if necessary.

Microbial analysis after recovery is required to verify proper water quality.

Option (D) Heat lines with line heaters

This option, a variation on option (C), utilizes line heaters to heat the piping . Although the overall effect is the same, the reliability and safety are lower for the line heaters.

Option (E) Shock with biocide

Shocking the system with a biocide is a simple option for microbial decontamination. It requires the ability to circulate the contaminated water, probably through the use of a jumper assembly.

The biocide selection is critical to this approach, since the crew safety must be a major concern. However, this approach is considered to be, with the exception of potential biofilm problems, an effective process. Following the biocide treatment, the water can be processed via options (1), (2), or (3) above, if necessary, to remove foreign matter and excess biocide concentrations.

Microbial analysis after recovery is required to verify proper water quality.

Option (F) Acoustic pipe wall cleaning

This option provides a means for removal of biofilms from the pipe walls. It is non-intrusive, can be performed as preventative measure (particularly for waste collection system), and requires little crew involvement.

The effectiveness for microbial control by this method alone is probably negligible. It is anticipated that use of this approach in conjunction with biocide or heat would be very effective. This approach is, however, considered very developmental. No data is available on the use of this approach.

APPENDIX C

The following tables support the water senstivity analysis performed in Section 5.0 of this report.

SSIPFSS WATER SENSITIVITY ANALYSIS - 90 DAY RESUPPLY

SPACE STATION WATER BALANCE PER 90 DAYS				
INPUTS:		WATER BALANCE,lbs		
Station Crew Size	8	ECLSS Potable	+	737
Water Balance Time Duration , Days	90	STS Potable Water	+	835
EVAs per balance duration, days	13	Station Potable Water	=	1572
EMU Loop Closure	CLOSED	Station EVA Water	-	0
Orbiter Crew Size	8	Lab Module Requirements	-	1242
Orbiter Crew on Station	4	Excess Water (Propulsion)	=	330
Orbiter Power Level ,Kw	10			
Orbiter Stay Duration,days	5	STS Waste Water*		144
Orbiter Visits per balance duration	1			
Scavenged Orbiter Storage Tank H20,lbm	0			
Food Water Content,lbm/man/day	1.1			
ECLSS CO2 Reduction Process	BOSCH			
ECLSS H2O Output, Lbm/man-days	0.93			
COL Water Requirement, Lbm/day	0			
JEM Water Requirement, Lbm/day	0			
USL Experiments Requirement ,lbm/day	13.8	*Not included in excess water		
USL Experiment Water Recovery,%	85			

SSIPFSS WATER SENSITIVITY ANALYSIS - SABATIER CO2 REDUCTION

SPACE STATION WATER BALANCE PER 90 DAYS				
INPUTS:		WATER BALANCE,lbs		
Station Crew Size	8	ECLSS Potable	+	206
Water Balance Time Duration , Days	90	STS Potable Water	+	1671
EVAs per balance duration, days	13	Station Potable Water	=	1877
EMU Loop Closure	CLOSED	Station EVA Water	-	0
Orbiter Crew Size	8	Lab Module Requirements	-	1242
Orbiter Crew on Station	4	Excess Water (Propulsion)	=	635
Orbiter Power Level ,Kw	10			
Orbiter Stay Duration,days	5	STS Waste Water*		288
Orbiter Visits per balance duration	2			
Scavenged Orbiter Storage Tank H20,lbm	0			
Food Water Content,lbm/man/day	1.1			
ECLSS CO2 Reduction Process	SABATIER			
ECLSS H2O Output, Lbm/man-days	0.26			
COL Water Requirement, Lbm/day	0			
JEM Water Requirement, Lbm/day	0			
USL Experiments Requirement ,lbm/day	13.8	*Not included in excess water		
USL Experiment Water Recovery,%	85			

SSIPFSS WATER SENSITIVITY ANALYSIS - 25% USL REQUIREMENTS

SPACE STATION WATER BALANCE PER 90 DAYS				
INPUTS:		WATER BALANCE,lbs		
Station Crew Size	8	ECLSS Potable	+	737
Water Balance Time Duration , Days	90	STS Potable Water	+	1671
EVAs per balance duration, days	13	Station Potable Water	=	2407
EMU Loop Closure	CLOSED	Station EVA Water	-	0
Orbiter Crew Size	8	Lab Module Requirements	-	1553
Orbiter Crew on Station	4	Excess Water (Propulsion)	=	855
Orbiter Power Level ,Kw	10			
Orbiter Stay Duration,days	5	STS Waste Water*		288
Orbiter Visits per balance duration	2			
Scavenged Orbiter Storage Tank H20,lbm	0			
Food Water Content,lbm/man/day	1.1			
ECLSS CO2 Reduction Process	BOSCH			
ECLSS H2O Output, Lbm/man-days	0.93			
COL Water Requirement, Lbm/day	0			
JEM Water Requirement, Lbm/day	0			
USL Experiments Requirement ,lbm/day	17.25	*Not included in excess water		
USL Experiment Water Recovery,%	85			

SSIPFSS WATER SENSITIVITY ANALYSIS - SHUTTLE EMU

SPACE STATION WATER BALANCE PER 90 DAYS				
INPUTS:		WATER BALANCE,lbs		
Station Crew Size	8	ECLSS Potable	+	737
Water Balance Time Duration , Days	90	STS Potable Water	+	1671
EVAs per balance duration, days	13	Station Potable Water	=	2407
EMU Loop Closure	OPEN	Station EVA Water	-	260
Orbiter Crew Size	8	Lab Module Requirements	-	1242
Orbiter Crew on Station	4	Excess Water (Propulsion)	=	905
Orbiter Power Level ,Kw	10			
Orbiter Stay Duration,days	5	STS Waste Water*		288
Orbiter Visits per balance duration	2			
Scavenged Orbiter Storage Tank H20,lbm	0			
Food Water Content,lbm/man/day	1.1			
ECLSS CO2 Reduction Process	BOSCH			
ECLSS H2O Output, Lbm/man-days	0.93			
COL Water Requirement, Lbm/day	0			
JEM Water Requirement, Lbm/day	0			
USL Experiments Requirement ,lbm/day	13.8	*Not included in excess water		
USL Experiment Water Recovery,%	85			

SSIPFSS WATER SENSITIVITY ANALYSIS - 25% STS CREW SIZE

SPACE STATION WATER BALANCE PER 90 DAYS				
INPUTS:		WATER BALANCE,lbs		
Station Crew Size	8	ECLSS Potable	+	737
Water Balance Time Duration , Days	90	STS Potable Water	+	1556
EVAs per balance duration, days	13	Station Potable Water	=	2293
EMU Loop Closure	CLOSED	Station EVA Water	-	0
Orbiter Crew Size	10	Lab Module Requirements	-	1242
Orbiter Crew on Station	4	Excess Water (Propulsion)	=	1051
Orbiter Power Level ,Kw	10			
Orbiter Stay Duration,days	5	STS Waste Water*		432
Orbiter Visits per balance duration	2			
Scavenged Orbiter Storage Tank H20,lbm	0			
Food Water Content,lbm/man/day	1.1			
ECLSS CO2 Reduction Process	BOSCH			
ECLSS H2O Output, Lbm/man-days	0.93			
COL Water Requirement, Lbm/day	0			
JEM Water Requirement, Lbm/day	0			
USL Experiments Requirement ,lbm/day	13.8	*Not included in excess water		
USL Experiment Water Recovery,%	85			

SSIPFSS WATER SENSITIVITY ANALYSIS - INTEGRATED JEM MODULE

SPACE STATION WATER BALANCE PER 90 DAYS				
INPUTS:		WATER BALANCE,lbs		
Station Crew Size	8	ECLSS Potable	+	737
Water Balance Time Duration , Days	90	STS Potable Water	+	1671
EVAs per balance duration, days	13	Station Potable Water	=	2407
EMU Loop Closure	CLOSED	Station EVA Water	-	0
Orbiter Crew Size	8	Lab Module Requirements	-	1242
Orbiter Crew on Station	4	Excess Water (Propulsion)	=	1075
Orbiter Power Level ,Kw	10			
Orbiter Stay Duration,days	5	STS Waste Water*		288
Orbiter Visits per balance duration	2			
Scavenged Orbiter Storage Tank H20,lbm	0			
Food Water Content,lbm/man/day	1.1			
ECLSS CO2 Reduction Process	BOSCH			
ECLSS H2O Output, Lbm/man-days	0.93			
COL Water Requirement, Lbm/day	0			
JEM Water Requirement, Lbm/day	1			
USL Experiments Requirement ,lbm/day	13.8	*Not included in excess water		
USL Experiment Water Recovery,%	85			

SSIPFSS WATER SENSITIVITY ANALYSIS -- + 25% STS CREW ON SPACE STATION

SPACE STATION WATER BALANCE PER 90 DAYS				
INPUTS:		WATER BALANCE,lbs		
Station Crew Size	8	ECLSS Potable	+	753
Water Balance Time Duration , Days	90	STS Potable Water	+	1728
EVAs per balance duration, days	13	Station Potable Water	=	2481
EMU Loop Closure	CLOSED	Station EVA Water	-	0
Orbiter Crew Size	8	Lab Module Requirements	-	1242
Orbiter Crew on Station	5	Excess Water (Propulsion)	=	1239
Orbiter Power Level ,Kw	10			
Orbiter Stay Duration,days	5	STS Waste Water*		216
Orbiter Visits per balance duration	2			
Scavenged Orbiter Storage Tank H20,lbm	0			
Food Water Content,lbm/man/day	1.1			
ECLSS CO2 Reduction Process	BOSCH			
ECLSS H2O Output, Lbm/man-days	0.93			
COL Water Requirement, Lbm/day	0			
JEM Water Requirement, Lbm/day	0			
USL Experiments Requirement ,lbm/day	13.8	*Not included in excess water		
USL Experiment Water Recovery,%	85			

SSIPFSS WATER SENSITIVITY ANALYSIS - - + 25% FOOD WATER CONTENT

SPACE STATION WATER BALANCE PER 90 DAYS				
INPUTS:		WATER BALANCE,lbs		
Station Crew Size	8	ECLSS Potable	+	954
Water Balance Time Duration , Days	90	STS Potable Water	+	1671
EVAs per balance duration, days	13	Station Potable Water	=	2625
EMU Loop Closure	CLOSED	Station EVA Water	-	0
Orbiter Crew Size	8	Lab Module Requirements	-	1242
Orbiter Crew on Station	4	Excess Water (Propulsion)	=	1383
Orbiter Power Level ,Kw	10			
Orbiter Stay Duration,days	5	STS Waste Water*		288
Orbiter Visits per balance duration	2			
Scavenged Orbiter Storage Tank H20,lbm	0			
Food Water Content,lbm/man/day	1.375			
ECLSS CO2 Reduction Process	BOSCH			
ECLSS H2O Output, Lbm/man-days	0.93			
COL Water Requirement, Lbm/day	0			
JEM Water Requirement, Lbm/day	0			
USL Experiments Requirement ,lbm/day	13.8	*Not included in excess water		
USL Experiment Water Recovery,%	85			

SSIPFSS WATER SENSITIVITY ANALYSIS - - + 25% STS DURATION AT SS

SPACE STATION WATER BALANCE PER 90 DAYS				
INPUTS:		WATER BALANCE,lbs		
Station Crew Size	8	ECLSS Potable	+	723
Water Balance Time Duration , Days	90	STS Potable Water	+	2089
EVAs per balance duration, days	13	Station Potable Water	=	2812
EMU Loop Closure	CLOSED	Station EVA Water	-	0
Orbiter Crew Size	8	Lab Module Requirements	-	1242
Orbiter Crew on Station	4	Excess Water (Propulsion)	=	1570
Orbiter Power Level ,Kw	10			
Orbiter Stay Duration,days	6.25	STS Waste Water*		360
Orbiter Visits per balance duration	2			
Scavenged Orbiter Storage Tank H20,lbm	0			
Food Water Content,lbm/man/day	1.1			
ECLSS CO2 Reduction Process	BOSCH			
ECLSS H2O Output, Lbm/man-days	0.93			
COL Water Requirement, Lbm/day	0			
JEM Water Requirement, Lbm/day	0			
USL Experiments Requirement ,lbm/day	13.8	*Not included in excess water		
USL Experiment Water Recovery,%	85			

SSIPFSS WATER SENSITIVITY ANALYSIS - - + 25% RESUPPLY PERIOD

SPACE STATION WATER BALANCE PER 90 DAYS				
INPUTS:		WATER BALANCE,lbs		
Station Crew Size	8	ECLSS Potable	+	737
Water Balance Time Duration , Days	90	STS Potable Water	+	2089
EVAs per balance duration, days	13	Station Potable Water	=	2825
EMU Loop Closure	CLOSED	Station EVA Water	-	0
Orbiter Crew Size	8	Lab Module Requirements	-	1242
Orbiter Crew on Station	4	Excess Water (Propulsion)	=	1583
Orbiter Power Level ,Kw	10			
Orbiter Stay Duration,days	5	STS Waste Water*		360
Orbiter Visits per balance duration	2.5			
Scavenged Orbiter Storage Tank H20,lbm	0			
Food Water Content,lbm/man/day	1.1			
ECLSS CO2 Reduction Process	BOSCH			
ECLSS H2O Output, Lbm/man-days	0.93			
COL Water Requirement, Lbm/day	0			
JEM Water Requirement, Lbm/day	0			
USL Experiments Requirement ,lbm/day	13.8	*Not included in excess water		
USL Experiment Water Recovery,%	85			

SSIPFSS WATER SENSITIVITY ANALYSIS - - + 25% STS FUEL CELL POWER

SPACE STATION WATER BALANCE PER 90 DAYS				
INPUTS:		WATER BALANCE,lbs		
Station Crew Size	8	ECLSS Potable	+	737
Water Balance Time Duration , Days	90	STS Potable Water	+	2146
EVAs per balance duration, days	13	Station Potable Water	=	2882
EMU Loop Closure	CLOSED	Station EVA Water	-	0
Orbiter Crew Size	8	Lab Module Requirements	-	1242
Orbiter Crew on Station	4	Excess Water (Propulsion)	=	1640
Orbiter Power Level ,Kw	12.5			
Orbiter Stay Duration,days	5	STS Waste Water*		288
Orbiter Visits per balance duration	2			
Scavenged Orbiter Storage Tank H20,lbm	0			
Food Water Content,lbm/man/day	1.1			
ECLSS CO2 Reduction Process	BOSCH			
ECLSS H2O Output, Lbm/man-days	0.93			
COL Water Requirement, Lbm/day	0			
JEM Water Requirement, Lbm/day	0			
USL Experiments Requirement ,lbm/day	13.8	*Not included in excess water		
USL Experiment Water Recovery,%	85			

SSIPFSS WATER SENSITIVITY ANALYSIS -- JSC FOOD WATER CONTENT

SPACE STATION WATER BALANCE PER 90 DAYS				
INPUTS:		WATER BALANCE,lbs		
Station Crew Size	8	ECLSS Potable	+	1608
Water Balance Time Duration , Days	90	STS Potable Water	+	1671
EVAs per balance duration, days	13	Station Potable Water	=	3279
EMU Loop Closure	CLOSED	Station EVA Water	-	0
Orbiter Crew Size	8	Lab Module Requirements	-	1242
Orbiter Crew on Station	4	Excess Water (Propulsion)	=	2037
Orbiter Power Level ,Kw	10			
Orbiter Stay Duration,days	5	STS Waste Water*		288
Orbiter Visits per balance duration	2			
Scavenged Orbiter Storage Tank H20,lbm	0			
Food Water Content,lbm/man/day	2.2			
ECLSS CO2 Reduction Process	BOSCH			
ECLSS H2O Output, Lbm/man-days	0.93			
COL Water Requirement, Lbm/day	0			
JEM Water Requirement, Lbm/day	0			
USL Experiments Requirement ,lbm/day	13.8	*Not included in excess water		
USL Experiment Water Recovery,%	85			

SSIPFSS WATER SENSITIVITY ANALYSIS -- MAX FOOD WATER CONTENT
(2.68 LBM/PERSON/DAY)

SPACE STATION WATER BALANCE PER 90 DAYS				
INPUTS:		WATER BALANCE.lbs		
Station Crew Size	8	ECLSS Potable	+	1988
Water Balance Time Duration , Days	90	STS Potable Water	+	1671
EVAs per balance duration, days	13	Station Potable Water	=	3659
EMU Loop Closure	CLOSED	Station EVA Water	-	0
Orbiter Crew Size	8	Lab Module Requirements	-	1242
Orbiter Crew on Station	4	Excess Water (Propulsion)	=	2417
Orbiter Power Level ,Kw	10			
Orbiter Stay Duration,days	5	STS Waste Water*		288
Orbiter Visits per balance duration	2			
Scavenged Orbiter Storage Tank H20,lbm	0			
Food Water Content,lbm/man/day	2.68			
ECLSS CO2 Reduction Process	BOSCH			
ECLSS H2O Output, Lbm/man-days	0.93			
COL Water Requirement, Lbm/day	0			
JEM Water Requirement, Lbm/day	0			
USL Experiments Requirement ,lbm/day	13.8	*Not included in excess water		
USL Experiment Water Recovery,%	85			

APPENDIX D

Integrated Nitrogen System Schematics and Components Lists

This appendix contains Figures D-1 through D-7 and Tables D-1 through D-24. The figures illustrate all of the INS configuration variants. Tables D-1 through D-19 list hardware for the INS configuration options that were investigated. Tables D-20 through D-24 list the hardware for the INS Storage Subsystem options.

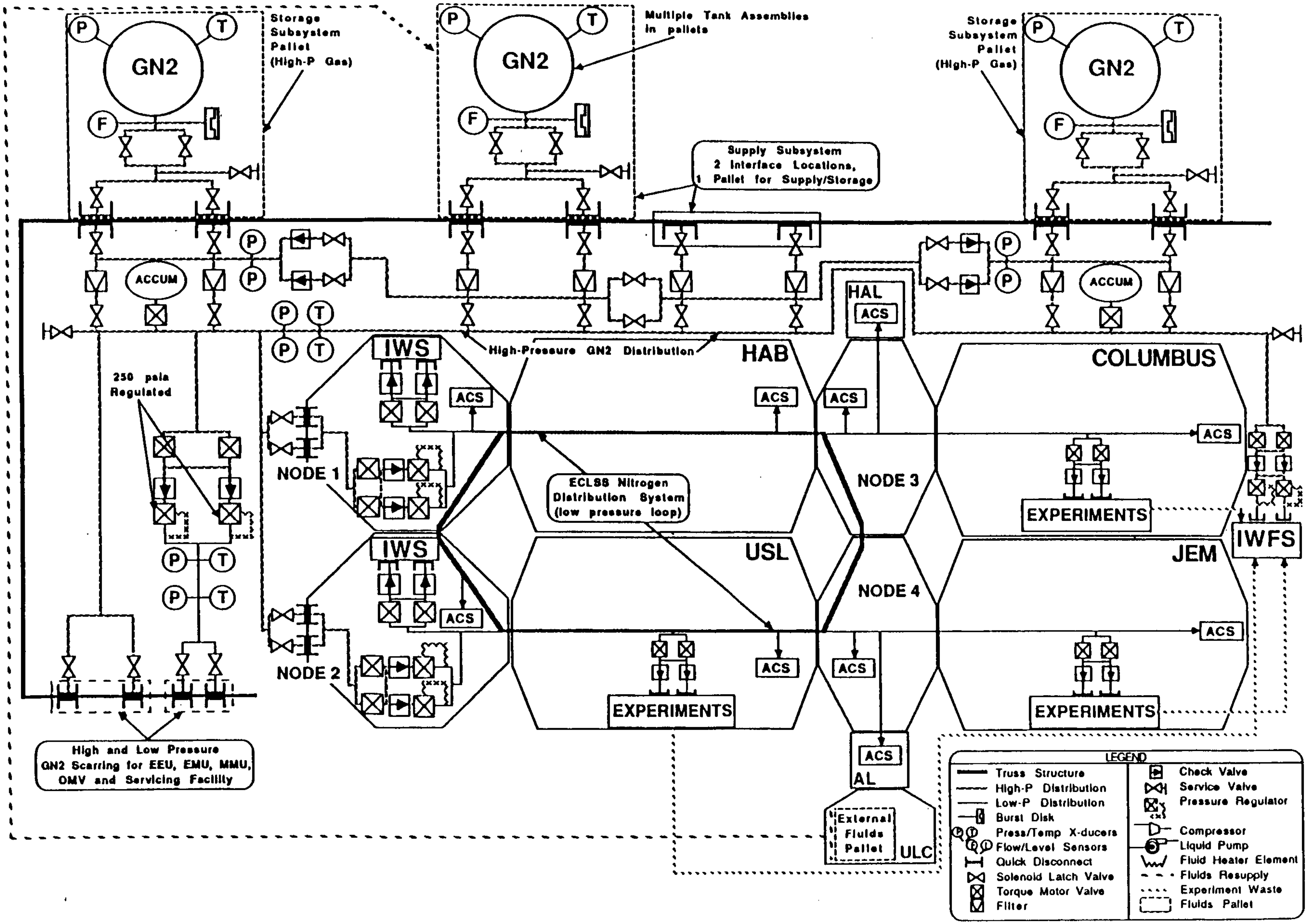

Figure D-1 INS Configuration #1 Schematic (High Pressure Gas Resupply without Delivery Compressors, Options 1A and 1C)

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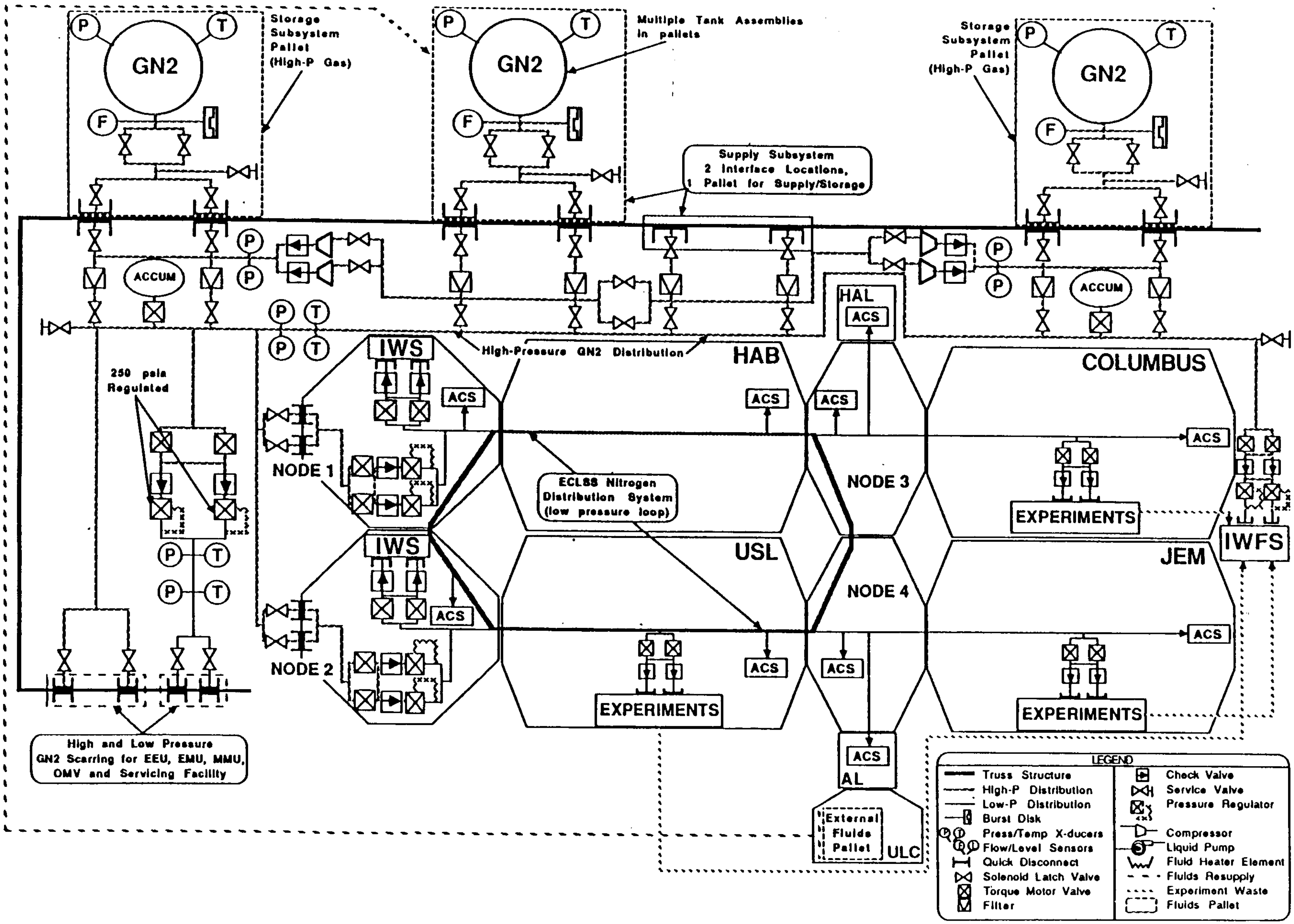

Figure D-2 INS Configuration #1 Schematic (High Pressure Gas Resupply with Delivery Compressors, Options 1B and 1D)

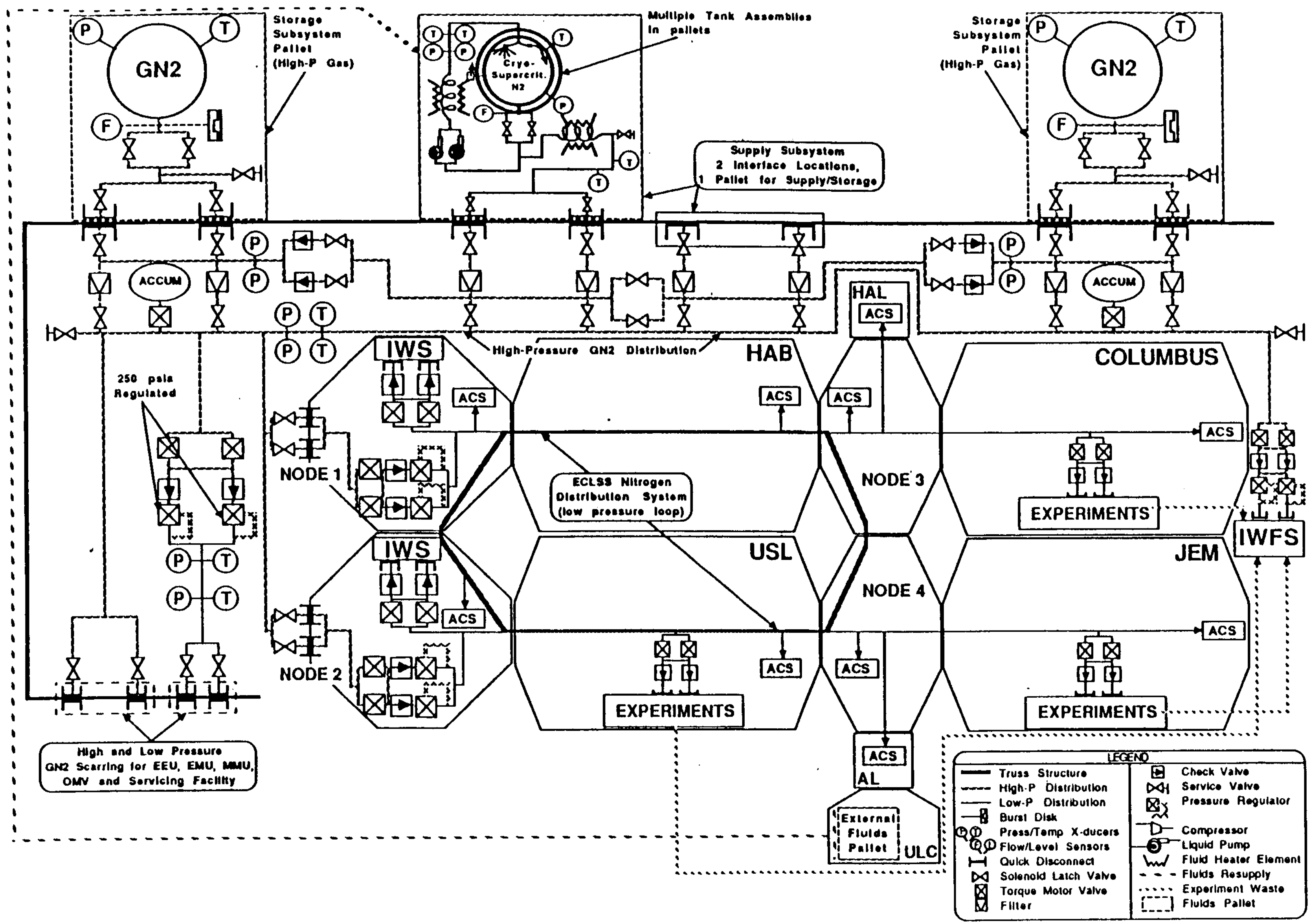

Figure D-3 INS Configuration #2 Schematic (Cryogenic-Supercritical Resupply without Delivery Compressors, Options 2A, 2C, and 2E)

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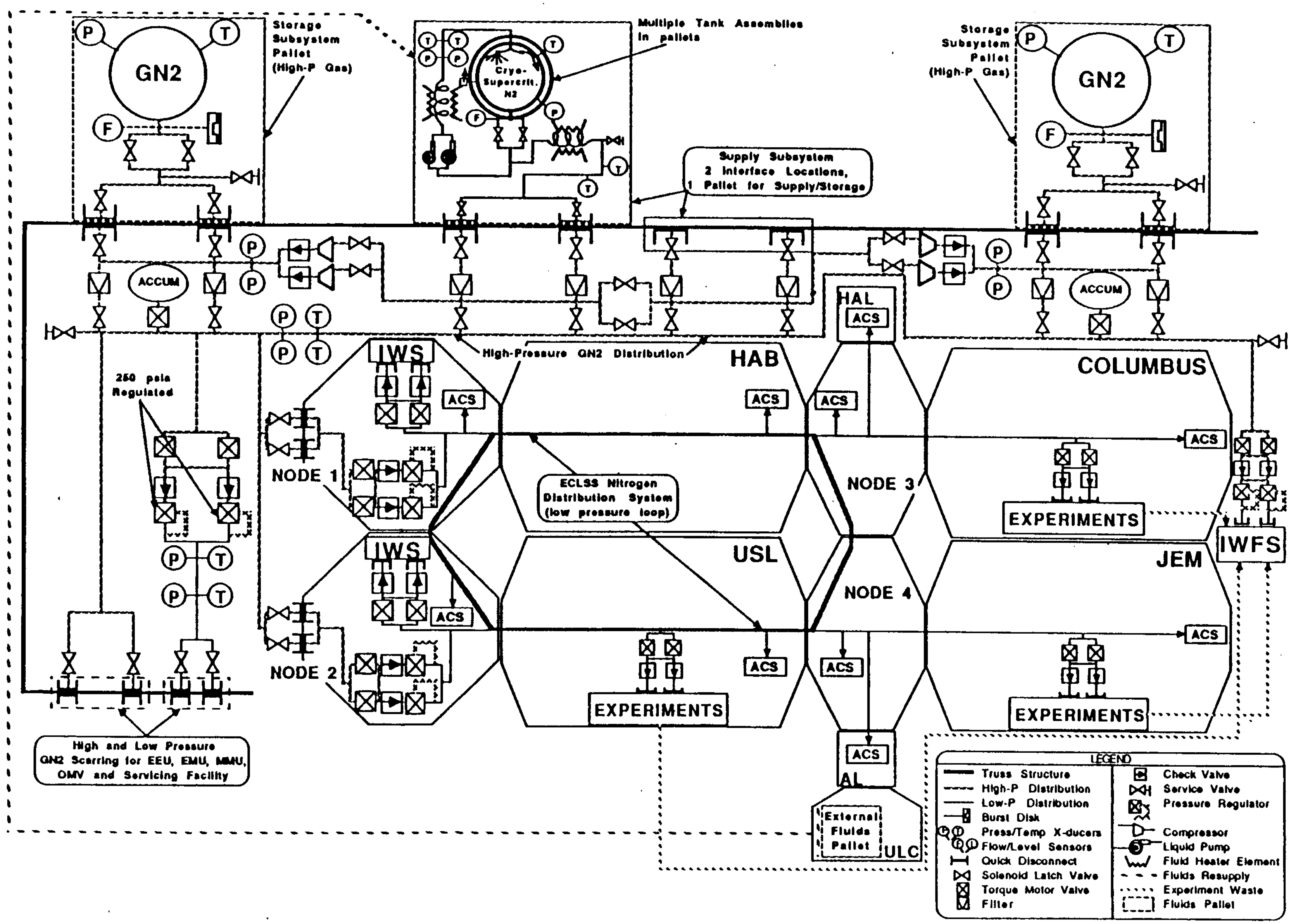

Figure D-4 INS Configuration #2 Schematic (Cryogenic-Supercritical Resupply with Delivery Compressors, Options 2B, 2D, and 2F)

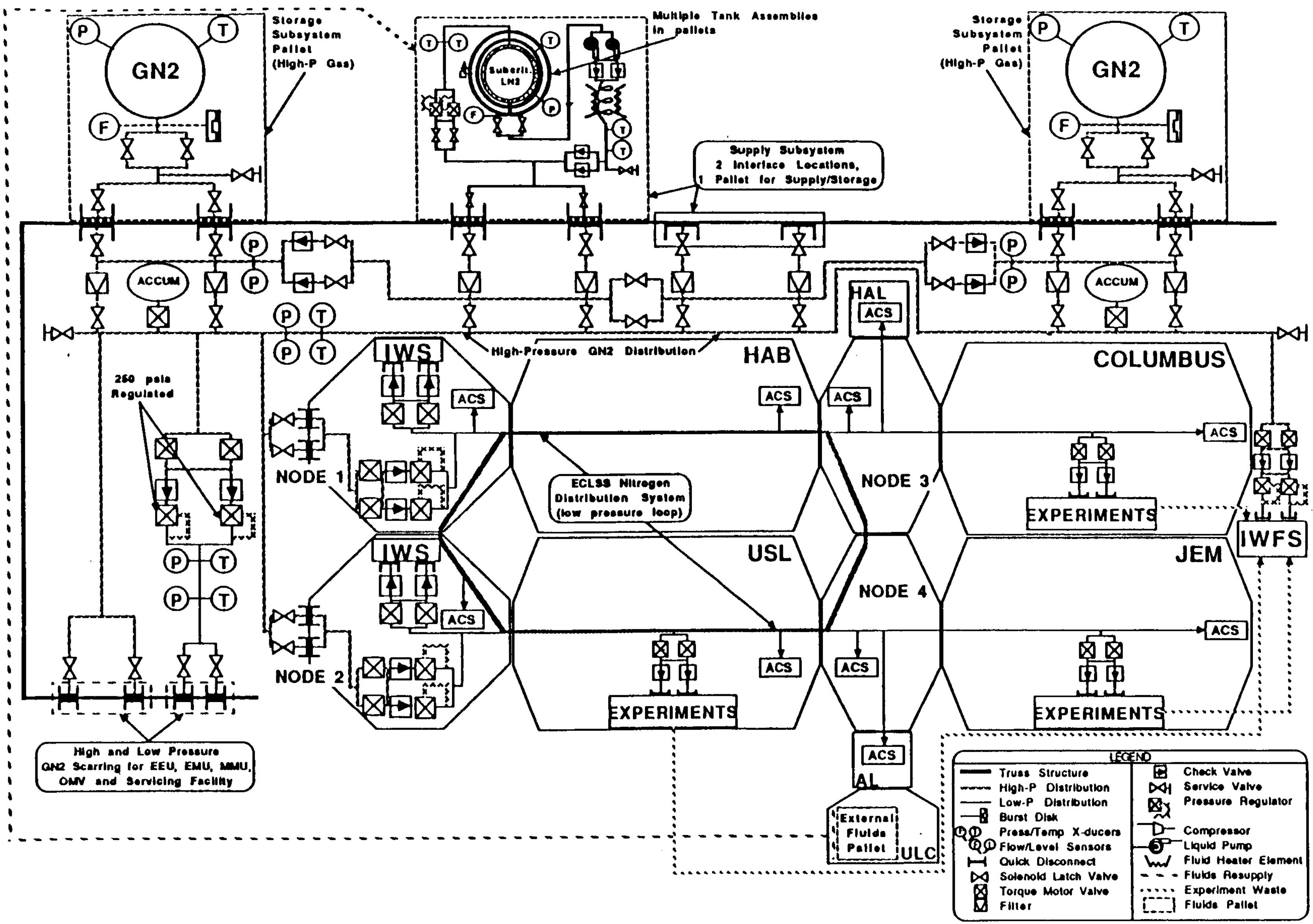

Figure D-5 INS Configuration #3 Schematic (Subcritical Liquid Resupply, Option 3)

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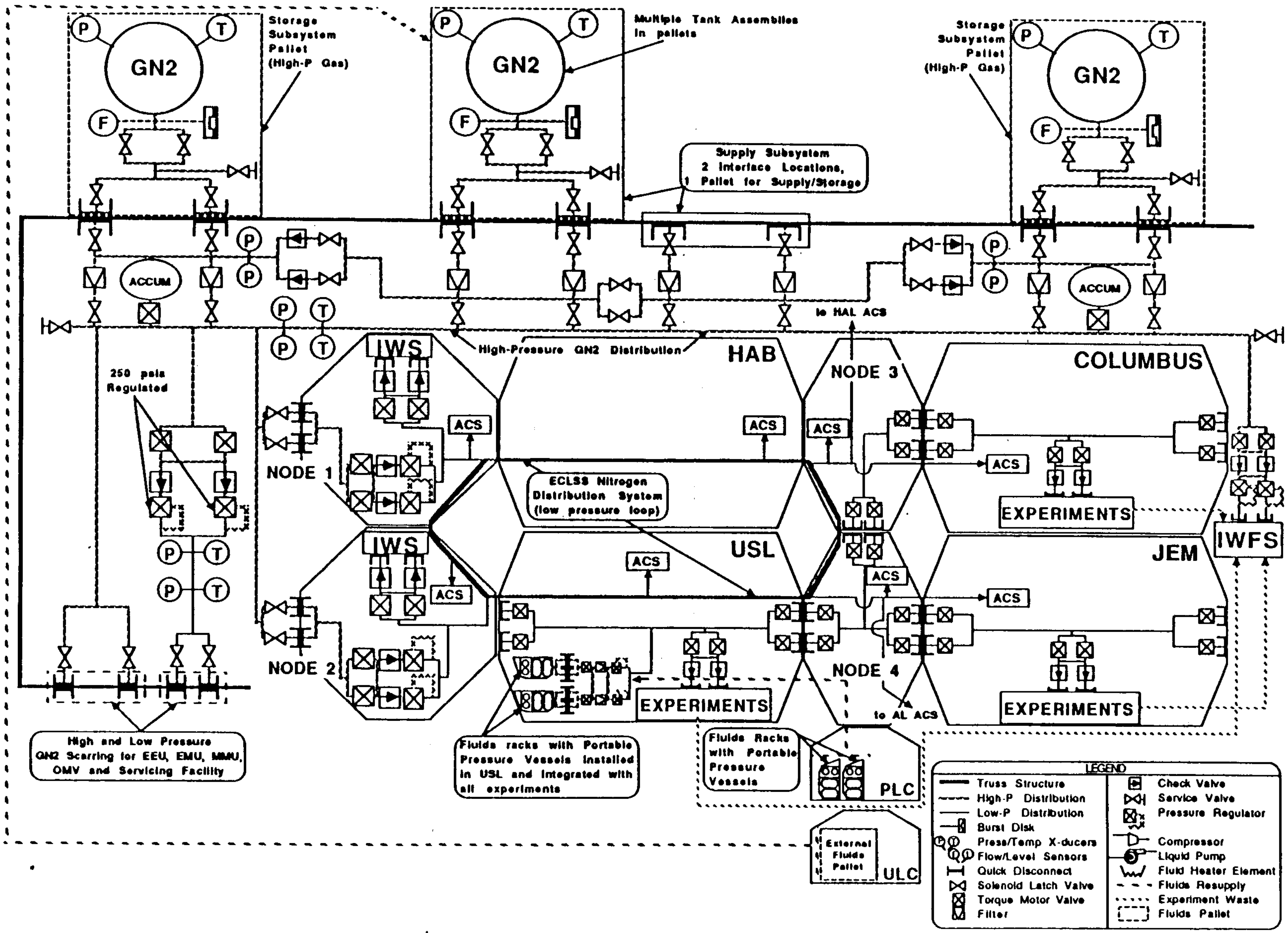

Figure D-6 INS Configuration #4 Schematic (Dedicated Gaseous Fluids Pallet(s) for Experiment Resupply, Options 4A - 4D)

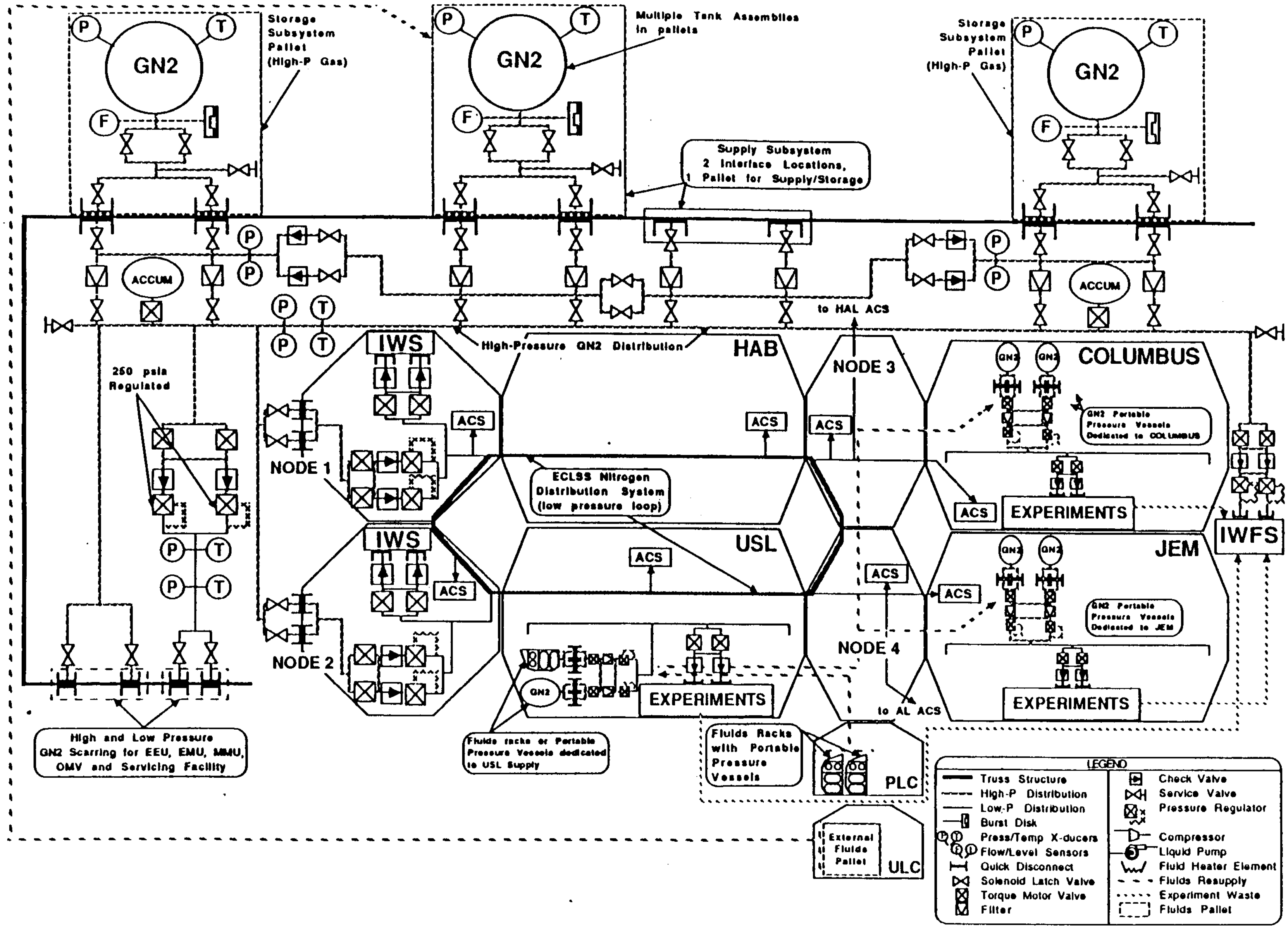

Figure D-7 INS Configuration #4 Schematic (Portable Pressure Vessels Dedicated to Experiments in Modules, Options 4E - 4H)

Table D-1 INS Option 1A Components List

Configuration 1A - Fully Integrated System - High Pressure Gaseous Resupply/Storage

INS Distribution Subsystem Component List - Option 1a

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Accumulator, nitrogen surge	2	0.375	3500	28.4	56.8	Located in node berthing locations
Disconnect, halves, nitrogen *	8	0.375	250/750	1.0	8.0	Buildup operations, growth interfaces
Disconnect, halves, nitrogen	18	0.375	3500	1.0	18.0	Buildup operations, growth interfaces
Valve, latching solenoid, nitrogen	2	0.375	250	0.8	1.6	Maximum flowrate = 30 lbm/hr
Valve, latching solenoid, nitrogen	28	0.375	3500	2.5	70.0	Maximum flowrate = 30 lbm/hr
Valve, torque motor, nitrogen *	4	0.375	200/750	3.3	13.2	Interface valving for IWS
Valve, torque motor, nitrogen	10	0.375	3500	3.3	33.0	Valving for system interfaces
Valve, check, nitrogen *	4	0.375	200/750	1.5	6.0	Prevention of IWS and experiment backup
Valve, check, nitrogen	12	0.375	3500	1.5	18.0	Check valves for user interfaces
Valve, fill and drain, nitrogen	2	0.375	3500	1.0	2.0	Nitrogen drain or disposal valve
Filter, inline, nitrogen gas	8	0.375	3500	1.0	8.0	Gas delivery purification filters
Regulator, electronic variable w/relief	4	0.375	3500 in, 200/750 out	6.0	24.0	Pressure control, shutoff capability req'd
Regulator, constant pressure w/relief	4	0.375	3500 in, 250 out	3.1	12.4	Pressure control, shutoff capability req'd
Sensor, pressure, nitrogen	2	0.375	250	0.4	0.8	Monitoring of scarred location
Sensor, pressure, nitrogen	6	0.375	3500	0.6	3.6	Compressor output, distribution pressure
Sensor, temperature, nitrogen	4	0.375	250/3500	0.4	1.6	Monitoring of scarred location
Compressor, nitrogen gas	2	0.375	250-1000	24.9	49.8	Potential for two transfer compressors***
Total Number of Components	118		Total Mass		277.0	lbm***

* Additional hardware required for experiments (quantity currently undetermined)
** Except where units are specified
*** Doesnt' include mass of potential transfer compressors

Table D-1 INS Option 1A Components List (continued)

INS Supply Subsystem Component List - Option 1a

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	1	44.44 cu. ft.	3500	597.0	597.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	1	0.375	3500 setpoint	1.5	1.5	Nitrogen tank relief for >3500 psia
Sensor, gas level, nitrogen	1	0.375	3500	0.8	0.8	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	4	0.375	3500	2.5	10.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	1	0.375	3500	1.0	1.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	2	0.375	3500	1.0	2.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	1	0.375	3500	0.6	0.6	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	1	0.375	3500	0.4	0.4	Pressure vessel storage monitoring
Heater, nitrogen tank	1	TBD	3500	0.5	0.5	Low power nitrogen gas tank heater
Total Number of Components	13		Total Mass		613.8	lbm
Total Supply and Distribution	131				890.8	lbm

* Initial resupply operating pressure
** Except where units are specified

INS Storage Subsystem Component List - Reference System - Option 1

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	848.8 cu. ft.	1000	3259.0	6518.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	1000 setpoint	1.5	3.0	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	1000	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	1000	2.5	20.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	1000	1.0	2.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	1000	1.0	4.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	1000	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	1000	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	1000	0.5	1.0	Low power nitrogen gas tank heater
Total Number of Components	26		Total Mass		6551.6	lbm
GRAND TOTALS	157				7442.4	lbm

* Operating pressure at full condition - the Storage Subsystem study evaluated pressures from 1000 to 8000 psia (shown is 1000 psia Reference System)
** Except where units are specified

Table D-2 INS Option 1B Components List

Configuration 1B - Fully Integrated System - High Pressure Gaseous Resupply/Storage

INS Distribution Subsystem Component List - Option 1b

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Accumulator, nitrogen surge	2	0.375	3500	28.4	56.8	Located in node berthing locations
Disconnect, halves, nitrogen *	8	0.375	250/750	1.0	8.0	Buildup operations, growth interfaces
Disconnect, halves, nitrogen	18	0.375	3500	1.0	18.0	Buildup operations, growth interfaces
Valve, latching solenoid, nitrogen	2	0.375	250	0.8	1.6	Maximum flowrate = 30 lbm/hr
Valve, latching solenoid, nitrogen	28	0.375	3500	2.5	70.0	Maximum flowrate = 30 lbm/hr
Valve, torque motor, nitrogen *	4	0.375	200/750	3.3	13.2	Interface valving for IWS
Valve, torque motor, nitrogen	10	0.375	3500	3.3	33.0	Valving for system interfaces
Valve, check, nitrogen *	4	0.375	200/750	1.5	6.0	Prevention of IWS and experiment backup
Valve, check, nitrogen	12	0.375	3500	1.5	18.0	Check valves for user interfaces
Valve, fill and drain, nitrogen	2	0.375	3500	1.0	2.0	Nitrogen drain or disposal valve
Filter, inline, nitrogen gas	8	0.375	3500	1.0	8.0	Gas delivery purification filters
Regulator, electronic variable w/relief	4	0.375	3500 in, 200/750 out	6.0	24.0	Pressure control, shutoff capability req'd
Regulator, constant pressure w/relief	4	0.375	3500 in, 250 out	3.1	12.4	Pressure control, shutoff capability req'd
Sensor, pressure, nitrogen	2	0.375	250	0.4	0.8	Monitoring of scarred location
Sensor, pressure, nitrogen	6	0.375	3500	0.6	3.6	Compressor output, distribution pressure
Sensor, temperature, nitrogen	4	0.375	250/3500	0.4	1.6	Monitoring of scarred location
Compressor, nitrogen gas	2	0.375	20-250/1000	24.9	49.8	Delivery or combination delivery/transfer
Compressor, nitrogen gas	2	0.375	20-1000	24.9	49.8	Potential for two transfer compressors***
Total Number of Components	120		Total Mass		326.8	lbm***

* Additional hardware required for experiments (quantity currently undetermined)
** Except where units are specified
*** Does n't include mass of potential transfer compressors

Table D-2 INS Option 1B Components List (continued)

INS Supply Subsystem Component List - Option 1b

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	1	40.97 cu. ft.	3500	551.0	551.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	1	0.375	3500 setpoint	1.5	1.5	Nitrogen tank relief for >3500 psia
Sensor, gas level, nitrogen	1	0.375	3500	0.8	0.8	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	4	0.375	3500	2.5	10.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	1	0.375	3500	1.0	1.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	2	0.375	3500	1.0	2.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	1	0.375	3500	0.6	0.6	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	1	0.375	3500	0.4	0.4	Pressure vessel storage monitoring
Heater, nitrogen tank	1	TBD	3500	0.5	0.5	Low power nitrogen gas tank heater
Total Number of Components	13		Total Mass		567.8	lbm
Total Supply and Distribution	133				894.6	lbm

* Initial resupply operating pressure
** Except where units are specified

INS Storage Subsystem Component List - Reference System - Option 1

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	848.8 cu. ft.	1000	3259.0	6518.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	1000 setpoint	1.5	3.0	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	1000	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	1000	2.5	20.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	1000	1.0	2.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	1000	1.0	4.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	1000	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	1000	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	1000	0.5	1.0	Low power nitrogen gas tank heater
Total Number of Components	26		Total Mass		6551.6	lbm
GRAND TOTALS	159				7446.2	lbm

* Operating pressure at full condition - the Storage Subsystem study evaluated pressures from 1000 to 8000 psia (shown is 1000 psia Reference System)
** Except where units are specified

Table D-3 INS Option 1C Components List

Configuration 1C - Fully Integrated System - Cryogenic-Supercritical Resupply/Storage

INS Distribution Subsystem Component List - Option 1c

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Accumulator, nitrogen surge	2	0.375	8000	78.8	157.6	Located in node berthing locations
Disconnect, halves, nitrogen *	8	0.375	250/750	1.0	8.0	Buildup operations, growth interfaces
Disconnect, halves, nitrogen	18	0.375	8000	1.1	19.8	Buildup operations, growth interfaces
Valve, latching solenoid, nitrogen	2	0.375	250	0.8	1.6	Maximum flowrate = 30 lbm/hr
Valve, latching solenoid, nitrogen	28	0.375	8000	2.6	72.8	Maximum flowrate = 30 lbm/hr
Valve, torque motor, nitrogen *	4	0.375	200/750	3.3	13.2	Interface valving for IWS
Valve, torque motor, nitrogen	10	0.375	8000	3.3	33.0	Valving for system interfaces
Valve, check, nitrogen *	4	0.375	200/750	1.5	6.0	Prevention of IWS and experiment backup
Valve, check, nitrogen	12	0.375	8000	1.5	18.0	Check valves for user interfaces
Valve, fill and drain, nitrogen	2	0.375	8000	1.1	2.2	Nitrogen drain or disposal valve
Filter, inline, nitrogen gas	8	0.375	8000	1.1	8.8	Gâs delivery purification filters
Regulator, electronic variable w/relief	4	0.375	8000 in, 200/750 out	6.0	24.0	Pressure control, shutoff capability req'd
Regulator, constant pressure w/relief	4	0.375	8000 in, 250 out	3.1	12.4	Pressure control, shutoff capability req'd
Sensor, pressure, nitrogen	2	0.375	250	0.4	0.8	Monitoring of scarred location
Sensor, pressure, nitrogen	6	0.375	8000	0.6	3.6	Compressor output, distribution pressure
Sensor, temperature, nitrogen	4	0.375	250/8000	0.4	1.6	Monitoring of scarred location
Compressor, nitrogen gas	2	0.375	250-1000	24.9	49.8	Potential for two transfer compressors***
Total Number of Components	118		Total Mass		383.4	lbm***

* Additional hardware required for experiments (quantity currently undetermined)
** Except where units are specified
*** Doesnt' include mass of potential transfer compressors

Table D-3 INS Option 1C Components List (continued)

INS Supply Subsystem Component List - Option 1c

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	1	24.13 cu. ft.	8000	741.0	741.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	1	0.375	8000 setpoint	3.9	3.9	Nitrogen tank relief for >8000 psia
Sensor, gas level, nitrogen	1	0.375	8000	0.8	0.8	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	4	0.375	8000	2.6	10.4	Tank and distribution system interface
Valve, fill and drain, nitrogen	1	0.375	8000	1.1	1.1	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	2	0.375	8000	1.1	2.2	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	1	0.375	8000	0.6	0.6	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	1	0.375	8000	0.4	0.4	Pressure vessel storage monitoring
Heater, nitrogen tank	1	TBD	8000	0.5	0.5	Low power nitrogen gas tank heater
Total Number of Components	13		Total Mass		760.9	lbm
Total Supply and Distribution	131				1144.3	lbm

* Initial resupply operating pressure
** Except where units are specified

INS Storage Subsystem Component List - Reference System - Option 1

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	848.8 cu. ft.	1000	3259.0	6518.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	1000 setpoint	1.5	3.0	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	1000	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	1000	2.5	20.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	1000	1.0	2.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	1000	1.0	4.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	1000	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	1000	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	1000	0.5	1.0	Low power nitrogen gas tank heater
Total Number of Components	26		Total Mass		6551.6	lbm
GRAND TOTALS	157				7695.9	lbm

* Operating pressure at full condition - the Storage Subsystem study evaluated pressures from 1000 to 8000 psia (shown is 1000 psia Reference System)
** Except where units are specified

Table D-4 INS Option 1D Components List

Configuration 1D - Fully Integrated System - High Pressure Gaseous Resupply/Storage

INS Distribution Subsystem Component List - Option 1d

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Accumulator, nitrogen surge	2	0.375	8000	78.8	157.6	Located in node berthing locations
Disconnect, halves, nitrogen *	8	0.375	250/750	1.0	8.0	Buildup operations, growth interfaces
Disconnect, halves, nitrogen	18	0.375	8000	1.1	19.8	Buildup operations, growth interfaces
Valve, latching solenoid, nitrogen	2	0.375	250	0.8	1.6	Maximum flowrate = 30 lbm/hr
Valve, latching solenoid, nitrogen	28	0.375	8000	2.6	72.8	Maximum flowrate = 30 lbm/hr
Valve, torque motor, nitrogen *	4	0.375	200/750	3.3	13.2	Interface valving for IWS
Valve, torque motor, nitrogen	10	0.375	8000	3.3	33.0	Valving for system interfaces
Valve, check, nitrogen *	4	0.375	200/750	1.5	6.0	Prevention of IWS and experiment backup
Valve, check, nitrogen	12	0.375	8000	1.5	18.0	Check valves for user interfaces
Valve, fill and drain, nitrogen	2	0.375	8000	1.1	2.2	Nitrogen drain or disposal valve
Filter, inline, nitrogen gas	8	0.375	8000	1.1	8.8	Gas delivery purification filters
Regulator, electronic variable w/relief	4	0.375	8000 in, 200/750 out	6.0	24.0	Pressure control, shutoff capability req'd
Regulator, constant pressure w/relief	4	0.375	8000 in, 250 out	3.1	12.4	Pressure control, shutoff capability req'd
Sensor, pressure, nitrogen	2	0.375	250	0.4	0.8	Monitoring of scarred location
Sensor, pressure, nitrogen	6	0.375	8000	0.6	3.6	Compressor output, distribution pressure
Sensor, temperature, nitrogen	4	0.375	250/8000	0.4	1.6	Monitoring of scarred location
Compressor, nitrogen gas	2	0.375	20-250/1000	24.9	49.8	Delivery or combination delivery/transfer
Compressor, nitrogen gas	2	0.375	20-1000	24.9	49.8	Potential for two transfer compressors***
Total Number of Components	120		Total Mass		433.2	lbm***

* Additional hardware required for experiments (quantity currently undetermined)
** Except where units are specified
*** Does n't include mass of potential transfer compressors

Table D-4 INS Option 1D Components List (continued)

INS Supply Subsystem Component List - Option 1d

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	1	23.07 cu. ft.	8000	709.0	709.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	1	0.375	8000 setpoint	3.9	3.9	Nitrogen tank relief for >8000 psia
Sensor, gas level, nitrogen	1	0.375	8000	0.8	0.8	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	4	0.375	8000	2.6	10.4	Tank and distribution system interface
Valve, fill and drain, nitrogen	1	0.375	8000	1.1	1.1	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	2	0.375	8000	1.1	2.2	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	1	0.375	8000	0.6	0.6	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	1	0.375	8000	0.4	0.4	Pressure vessel storage monitoring
Heater, nitrogen tank	1	TBD	8000	0.5	0.5	Low power nitrogen gas tank heater
Total Number of Components	13		Total Mass		728.9	lbm
Total Supply and Distribution	133				1162.1	lbm

* Initial resupply operating pressure
** Except where units are specified

INS Storage Subsystem Component List - Reference System - Option 1

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	848.8 cu. ft.	1000	3259.0	6518.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	1000 setpoint	1.5	3.0	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	1000	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	1000	2.5	20.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	1000	1.0	2.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	1000	1.0	4.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	1000	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	1000	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	1000	0.5	1.0	Low power nitrogen gas tank heater
Total Number of Components	26		Total Mass		6551.6	lbm
GRAND TOTALS	159				7713.7	lbm

* Operating pressure at full condition - the Storage Subsystem study evaluated pressures from 1000 to 8000 psia (shown is 1000 psia Reference System)
** Except where units are specified

Table D-5 INS Option 2A Components List

Configuration 2A - Fully Integrated System - Cryogenic-Supercritical Resupply/Storage

INS Distribution Subsystem Component List - Option 2a

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Accumulator, nitrogen surge	2	0.375	1000	20.9	41.8	Located in node berthing locations
Disconnect, halves, nitrogen *	8	0.375	250/750	1.0	8.0	Buildup operations, growth interfaces
Disconnect, halves, nitrogen	18	0.375	1000	1.0	18.0	Buildup operations, growth interfaces
Valve, latching solenoid, nitrogen	2	0.375	250	0.8	1.6	Maximum flowrate = 30 lbm/hr
Valve, latching solenoid, nitrogen	28	0.375	1000	2.5	70.0	Maximum flowrate = 30 lbm/hr
Valve, torque motor, nitrogen *	4	0.375	200/750	3.3	13.2	Interface valving for IWS
Valve, torque motor, nitrogen	10	0.375	1000	3.3	33.0	Valving for system interfaces
Valve, check, nitrogen *	4	0.375	200/750	1.5	6.0	Prevention of IWS and experiment backup
Valve, check, nitrogen	12	0.375	1000	1.5	18.0	Check valves for user interfaces
Valve, fill and drain, nitrogen	2	0.375	1000	1.0	2.0	Nitrogen drain or disposal valve
Filter, inline, nitrogen gas	8	0.375	1000	1.0	8.0	Gas delivery purification filters
Regulator, electronic variable w/relief	4	0.375	1000 in, 200/750 out	6.0	24.0	Pressure control, shutoff capability req'd
Regulator, constant pressure w/relief	4	0.375	1000 in, 250 out	3.1	12.4	Pressure control, shutoff capability req'd
Sensor, pressure, nitrogen	2	0.375	250	0.4	0.8	Monitoring of scarred location
Sensor, pressure, nitrogen	6	0.375	1000	0.6	3.6	Compressor output, distribution pressure
Sensor, temperature, nitrogen	4	0.375	250/1000	0.4	1.6	Monitoring of scarred location
Compressor, nitrogen gas	2	0.375	250/530-1000	24.9	49.8	Req'd for transfer to storage subsystem
Total Number of Components	120		Total Mass		311.8	lbm

* Additional hardware required for experiments (quantity currently undetermined)

** Except where units are specified

Table D-5 INS Option 2A Components List (continued)

INS Supply Subsystem Component List - Option 2a

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	1	16.52 cu. ft.	530	292.0	292.0	Vacuum-jacketed pressure vessel
Valve, vent relief, nitrogen	1	0.375	530 setpoint	1.5	1.5	Nitrogen tank relief for >530 psia
Sensor, flowmeter/level, nitrogen	1	0.375	530	0.8	0.8	Method for cryo-supercritical using P, T
Valve, latching solenoid, nitrogen	4	0.375	530	2.5	10.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	1	0.375	530	1.0	1.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	2	0.375	530	1.0	2.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	3	0.375	530	0.6	1.8	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	5	0.375	530	0.4	2.0	Pressure vessel storage monitoring
Pumps, recirculating, nitrogen	2	0.375	530	20.0	40.0	Recirculator pumps with low head
Heaters, conditioning, nitrogen	4	0.375	530	3.9	15.6	Heaters for tank and delivery conditioning
Total Number of Components	24		Total Mass		366.7	lbm
Total Supply and Distribution	144				678.5	lbm

* Initial resupply operating pressure
** Except where units are specified

INS Storage Subsystem Component List - Reference System - Option 1

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	848.8 cu. ft.	1000	3259.0	6518.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	1000 setpoint	1.5	3.0	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	1000	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	1000	2.5	20.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	1000	1.0	2.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	1000	1.0	4.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	1000	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	1000	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	1000	0.5	1.0	Low power nitrogen gas tank heater
Total Number of Components	26		Total Mass		6551.6	lbm
GRAND TOTALS	170				7230.1	lbm

* Operating pressure at full condition - the Storage Subsystem study evaluated pressures from 1000 to 8000 psia (shown is 1000 psia Reference System)
** Except where units are specified

Table D-6 INS Option 2B Components List

Configuration 2B - Fully Integrated System - Cryogenic-Supercritical Resupply/Storage

INS Distribution Subsystem Component List - Option 2b

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Accumulator, nitrogen surge	2	0.375	1000	20.9	41.8	Located in node berthing locations
Disconnect, halves, nitrogen *	8	0.375	250/750	1.0	8.0	Buildup operations, growth interfaces
Disconnect, halves, nitrogen	18	0.375	1000	1.0	18.0	Buildup operations, growth interfaces
Valve, latching solenoid, nitrogen	2	0.375	250	0.8	1.6	Maximum flowrate = 30 lbm/hr
Valve, latching solenoid, nitrogen	28	0.375	1000	2.5	70.0	Maximum flowrate = 30 lbm/hr
Valve, torque motor, nitrogen *	4	0.375	200/750	3.3	13.2	Interface valving for IWS
Valve, torque motor, nitrogen	10	0.375	1000	3.3	33.0	Valving for system interfaces
Valve, check, nitrogen *	4	0.375	200/750	1.5	6.0	Prevention of IWS and experiment backup
Valve, check, nitrogen	12	0.375	1000	1.5	18.0	Check valves for user interfaces
Valve, fill and drain, nitrogen	2	0.375	1000	1.0	2.0	Nitrogen drain or disposal valve
Filter, inline, nitrogen gas	8	0.375	1000	1.0	8.0	Gas delivery purification filters
Regulator, electronic variable w/relief	4	0.375	1000 in, 200/750 out	6.0	24.0	Pressure control, shutoff capability req'd
Regulator, constant pressure w/relief	4	0.375	1000 in, 250 out	3.1	12.4	Pressure control, shutoff capability req'd
Sensor, pressure, nitrogen	2	0.375	250	0.4	0.8	Monitoring of scarred location
Sensor, pressure, nitrogen	6	0.375	1000	0.6	3.6	Compressor output, distribution pressure
Sensor, temperature, nitrogen	4	0.375	250/1000	0.4	1.6	Monitoring of scarred location
Compressor, nitrogen gas	2	0.375	20-250/1000	24.9	49.8	Delivery or combination delivery/transfer
Compressor, nitrogen gas	2	0.375	20-1000	24.9	49.8	Potential for two transfer compressors***
Total Number of Components	120		Total Mass		311.8	lbm***

* Additional hardware required for experiments (quantity currently undetermined)

** Except where units are specified

*** Does not include mass of potential transfer compressors

Table D-6 INS Option 2B Components List (continued)

INS Supply Subsystem Component List - Option 2b

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	1	16.01 cu. ft.	530	284.0	284.0	Vacuum-jacketed pressure vessel
Valve, vent relief, nitrogen	1	0.375	530 setpoint	1.5	1.5	Nitrogen tank relief for >530 psia
Sensor, flowmeter/level, nitrogen	1	0.375	530	0.8	0.8	Method for cryo-supercritical using P, T
Valve, latching solenoid, nitrogen	4	0.375	530	2.5	10.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	1	0.375	530	1.0	1.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	2	0.375	530	1.0	2.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	3	0.375	530	0.6	1.8	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	5	0.375	530	0.4	2.0	Pressure vessel storage monitoring
Pumps, recirculating, nitrogen	2	0.375	530	20.0	40.0	Recirculator pumps with low head
Heaters, conditioning, nitrogen	4	0.375	530	3.9	15.6	Heaters for tank and delivery conditioning
Total Number of Components	24		Total Mass		358.7	lbm
Total Supply and Distribution	144				670.5	lbm

* Initial resupply operating pressure
** Except where units are specified

INS Storage Subsystem Component List - Reference System - Option 1

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	848.8 cu. ft.	1000	3259.0	6518.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	1000 setpoint	1.5	3.0	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	1000	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	1000	2.5	20.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	1000	1.0	2.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	1000	1.0	4.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	1000	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	1000	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	1000	0.5	1.0	Low power nitrogen gas tank heater
Total Number of Components	26		Total Mass		6551.6	lbm
GRAND TOTALS	170				7222.1	lbm

* Operating pressure at full condition - the Storage Subsystem study evaluated pressures from 1000 to 8000 psia (shown is 1000 psia Reference System)
** Except where units are specified

Table D-7 INS Option 2C Components List

Configuration 2C - Fully Integrated System - High Pressure Gaseous Resupply/Storage

INS Distribution Subsystem Component List - Option 2c

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Accumulator, nitrogen surge	2	0.375	1000	20.9	41.8	Located in node berthing locations
Disconnect, halves, nitrogen *	8	0.375	250/750	1.0	8.0	Buildup operations, growth interfaces
Disconnect, halves, nitrogen	18	0.375	1000	1.0	18.0	Buildup operations, growth interfaces
Valve, latching solenoid, nitrogen	2	0.375	250	0.8	1.6	Maximum flowrate = 30 lbm/hr
Valve, latching solenoid, nitrogen	28	0.375	1000	2.5	70.0	Maximum flowrate = 30 lbm/hr
Valve, torque motor, nitrogen *	4	0.375	200/750	3.3	13.2	Interface valving for IWS
Valve, torque motor, nitrogen	10	0.375	1000	3.3	33.0	Valving for system interfaces
Valve, check, nitrogen *	4	0.375	200/750	1.5	6.0	Prevention of IWS and experiment backup
Valve, check, nitrogen	12	0.375	1000	1.5	18.0	Check valves for user interfaces
Valve, fill and drain, nitrogen	2	0.375	1000	1.0	2.0	Nitrogen drain or disposal valve
Filter, inline, nitrogen gas	8	0.375	1000	1.0	8.0	Gas delivery purification filters
Regulator, electronic variable w/relief	4	0.375	1000 in, 200/750 out	6.0	24.0	Pressure control, shutoff capability req'd
Regulator, constant pressure w/relief	4	0.375	1000 in, 250 out	3.1	12.4	Pressure control, shutoff capability req'd
Sensor, pressure, nitrogen	2	0.375	250	0.4	0.8	Monitoring of scarred location
Sensor, pressure, nitrogen	6	0.375	1000	0.6	3.6	Compressor output, distribution pressure
Sensor, temperature, nitrogen	4	0.375	250/1000	0.4	1.6	Monitoring of scarred location
Compressor, nitrogen gas	2	0.375	250/600-1000	24.9	49.8	Req'd for transfer to storage subsystem
Total Number of Components	120		Total Mass		311.8	lbm

* Additional hardware required for experiments (quantity currently undetermined)
** Except where units are specified

Table D-7 INS Option 2C Components List (continued)

INS Supply Subsystem Component List - Option 2c

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	1	16.39 cu. ft.	600	290.0	290.0	Vacuum-jacketed pressure vessel
Valve, vent relief, nitrogen	1	0.375	600 setpoint	1.5	1.5	Nitrogen tank relief for >600 psia
Sensor, flowmeter/level, nitrogen	1	0.375	600	0.8	0.8	Method for cryo-supercritical using P, T
Valve, latching solenoid, nitrogen	4	0.375	600	2.5	10.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	1	0.375	600	1.0	1.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	2	0.375	600	1.0	2.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	3	0.375	600	0.6	1.8	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	5	0.375	600	0.4	2.0	Pressure vessel storage monitoring
Pumps, recirculating, nitrogen	2	0.375	600	20.0	40.0	Recirculator pumps with low head
Heaters, conditioning, nitrogen	4	0.375	600	3.9	15.6	Heaters for tank and delivery conditioning
Total Number of Components	24		Total Mass		364.7	lbm
Total Supply and Distribution	144				676.5	lbm

* Initial resupply operating pressure
** Except where units are specified

INS Storage Subsystem Component List - Reference System - Option 1

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	848.8 cu. ft.	1000	3259.0	6518.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	1000 setpoint	1.5	3.0	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	1000	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	1000	2.5	20.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	1000	1.0	2.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	1000	1.0	4.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	1000	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	1000	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	1000	0.5	1.0	Low power nitrogen gas tank heater
Total Number of Components	26		Total Mass		6551.6	lbm
GRAND TOTALS	170				7228.1	lbm

* Operating pressure at full condition - the Storage Subsystem study evaluated pressures from 1000 to 8000 psia (shown is 1000 psia Reference System)
** Except where units are specified

Table D-8 INS Option 2D Components List

Configuration 2D - Fully Integrated System - Cryogenic-Supercritical Resupply/Storage

INS Distribution Subsystem Component List - Option 2d

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Accumulator, nitrogen surge	2	0.375	1000	20.9	41.8	Located in node berthing locations
Disconnect, halves, nitrogen *	8	0.375	250/750	1.0	8.0	Buildup operations, growth interfaces
Disconnect, halves, nitrogen	18	0.375	1000	1.0	18.0	Buildup operations, growth interfaces
Valve, latching solenoid, nitrogen	2	0.375	250	0.8	1.6	Maximum flowrate = 30 lbm/hr
Valve, latching solenoid, nitrogen	28	0.375	1000	2.5	70.0	Maximum flowrate = 30 lbm/hr
Valve, torque motor, nitrogen *	4	0.375	200/750	3.3	13.2	Interface valving for IWS
Valve, torque motor, nitrogen	10	0.375	1000	3.3	33.0	Valving for system interfaces
Valve, check, nitrogen *	4	0.375	200/750	1.5	6.0	Prevention of IWS and experiment backup
Valve, check, nitrogen	12	0.375	1000	1.5	18.0	Check valves for user interfaces
Valve, fill and drain, nitrogen	2	0.375	1000	1.0	2.0	Nitrogen drain or disposal valve
Filter, inline, nitrogen gas	8	0.375	1000	1.0	8.0	Gas delivery purification filters
Regulator, electronic variable w/relief	4	0.375	1000 in, 200/750 out	6.0	24.0	Pressure control, shutoff capability req'd
Regulator, constant pressure w/relief	4	0.375	1000 in, 250 out	3.1	12.4	Pressure control, shutoff capability req'd
Sensor, pressure, nitrogen	2	0.375	250	0.4	0.8	Monitoring of scarred location
Sensor, pressure, nitrogen	6	0.375	1000	0.6	3.6	Compressor output, distribution pressure
Sensor, temperature, nitrogen	4	0.375	250/1000	0.4	1.6	Monitoring of scarred location
Compressor, nitrogen gas	2	0.375	20-250/1000	24.9	49.8	Delivery or combination delivery/transfer
Compressor, nitrogen gas	2	0.375	20-1000	24.9	49.8	Potential for two transfer compressors***
Total Number of Components	120		Total Mass		311.8	lbm***

* Additional hardware required for experiments (quantity currently undetermined)
** Except where units are specified
*** Does not include mass of potential transfer compressors

Table D-8 INS Option 2D Components List (continued)

INS Supply Subsystem Component List - Option 2d

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	1	15.89 cu. ft.	600	283.0	283.0	Vacuum-jacketed pressure vessel
Valve, vent relief, nitrogen	1	0.375	600 setpoint	1.5	1.5	Nitrogen tank relief for >600 psia
Sensor, flowmeter/level, nitrogen	1	0.375	600	0.8	0.8	Method for cryo-supercritical using P, T
Valve, latching solenoid, nitrogen	4	0.375	600	2.5	10.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	1	0.375	600	1.0	1.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	2	0.375	600	1.0	2.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	3	0.375	600	0.6	1.8	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	5	0.375	600	0.4	2.0	Pressure vessel storage monitoring
Pumps, recirculating, nitrogen	2	0.375	600	20.0	40.0	Recirculator pumps with low head
Heaters, conditioning, nitrogen	4	0.375	600	3.9	15.6	Heaters for tank and delivery conditioning
Total Mass	24		Total Mass		357.7	lbm
Total Supply and Distribution	144				669.5	lbm

* Initial resupply operating pressure
** Except where units are specified

INS Storage Subsystem Component List - Reference System - Option 1

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	848.8 cu. ft.	1000	3259.0	6518.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	1000 setpoint	1.5	3.0	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	1000	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	1000	2.5	20.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	1000	1.0	2.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	1000	1.0	4.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	1000	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	1000	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	1000	0.5	1.0	Low power nitrogen gas tank heater
Total Number of Components	26				6551.6	lbm
GRAND TOTALS	170				7221.1	lbm

* Operating pressure at full condition - the Storage Subsystem study evaluated pressures from 1000 to 8000 psia (shown is 1000 psia Reference System)
** Except where units are specified

Table D-9 INS Option 2E Components List

Configuration 2E - Fully Integrated System - Cryogenic-Supercritical Resupply/Storage

INS Distribution Subsystem Component List - Option 2e

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Accumulator, nitrogen surge	2	0.375	1000	20.9	41.8	Located in node berthing locations
Disconnect, halves, nitrogen *	8	0.375	250/750	1.0	8.0	Buildup operations, growth interfaces
Disconnect, halves, nitrogen	18	0.375	1000	1.0	18.0	Buildup operations, growth interfaces
Valve, latching solenoid, nitrogen	2	0.375	250	0.8	1.6	Maximum flowrate = 30 lbm/hr
Valve, latching solenoid, nitrogen	28	0.375	1000	2.5	70.0	Maximum flowrate = 30 lbm/hr
Valve, torque motor, nitrogen *	4	0.375	200/750	3.3	13.2	Interface valving for IWS
Valve, torque motor, nitrogen	10	0.375	1000	3.3	33.0	Valving for system interfaces
Valve, check, nitrogen *	4	0.375	200/750	1.5	6.0	Prevention of IWS and experiment backup
Valve, check, nitrogen	12	0.375	1000	1.5	18.0	Check valves for user interfaces
Valve, fill and drain, nitrogen	2	0.375	1000	1.0	2.0	Nitrogen drain or disposal valve
Filter, inline, nitrogen gas	8	0.375	1000	1.0	8.0	Gas delivery purification filters
Regulator, electronic variable w/relief	4	0.375	1000 in, 200/750 out	6.0	24.0	Pressure control, shutoff capability req'd
Regulator, constant pressure w/relief	4	0.375	1000 in, 250 out	3.1	12.4	Pressure control, shutoff capability req'd
Sensor, pressure, nitrogen	2	0.375	250	0.4	0.8	Monitoring of scarred location
Sensor, pressure, nitrogen	6	0.375	1000	0.6	3.6	Compressor output, distribution pressure
Sensor, temperature, nitrogen	4	0.375	250/1000	0.4	1.6	Monitoring of scarred location
Compressor, nitrogen gas	2	0.375	250/530-1000	24.9	49.8	Potential for two transfer compressors***
Total Number of Components	118		Total Mass		262.0	lbm***

* Additional hardware required for experiments (quantity currently undetermined)
** Except where units are specified
*** Does not include mass of potential transfer compressors

Table D-9 INS Option 2E Components List (continued)

INS Supply Subsystem Component List - Option 2e

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	1	15.84 cu. ft.	1000	305.0	305.0	Vacuum-jacketed pressure vessel
Valve, vent relief, nitrogen	1	0.375	1000 setpoint	1.5	1.5	Nitrogen tank relief for >1000 psia
Sensor, flowmeter/level, nitrogen	1	0.375	1000	0.8	0.8	Method for cryo-supercritical using P, T
Valve, latching solenoid, nitrogen	4	0.375	1000	2.5	10.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	1	0.375	1000	1.0	1.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	2	0.375	1000	1.0	2.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	3	0.375	1000	0.6	1.8	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	5	0.375	1000	0.4	2.0	Pressure vessel storage monitoring
Pumps, recirculating, nitrogen	2	0.375	1000	20.0	40.0	Recirculator pumps with low head
Heaters, conditioning, nitrogen	4	0.375	1000	3.9	15.6	Heaters for tank and delivery conditioning
Total Number of Components	24		Total Mass		379.7	lbm
Total Supply and Distribution	142				641.7	lbm

* Initial resupply operating pressure
** Except where units are specified

INS Storage Subsystem Component List - Reference System - Option 1

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	848.8 cu. ft.	1000	3259.0	6518.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	1000 setpoint	1.5	3.0	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	1000	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	1000	2.5	20.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	1000	1.0	2.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	1000	1.0	4.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	1000	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	1000	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	1000	0.5	1.0	Low power nitrogen gas tank heater
Total Number of Components	26		Total Mass		6551.6	lbm
GRAND TOTALS	168				7193.3	lbm

* Operating pressure at full condition - the Storage Subsystem study evaluated pressures from 1000 to 8000 psia (shown is 1000 psia Reference System)
** Except where units are specified

Table D-10 INS Option 2F Components List

Configuration 2F - Fully Integrated System - Cryogenic-Supercritical Resupply/Storage

INS Distribution Subsystem Component List - Option 2f

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Accumulator, nitrogen surge	2	0.375	1000	20.9	41.8	Located in node berthing locations
Disconnect, halves, nitrogen *	8	0.375	250/750	1.0	8.0	Buildup operations, growth interfaces
Disconnect, halves, nitrogen	18	0.375	1000	1.0	18.0	Buildup operations, growth interfaces
Valve, latching solenoid, nitrogen	2	0.375	250	0.8	1.6	Maximum flowrate = 30 lbm/hr
Valve, latching solenoid, nitrogen	28	0.375	1000	2.5	70.0	Maximum flowrate = 30 lbm/hr
Valve, torque motor, nitrogen *	4	0.375	200/750	3.3	13.2	Interface valving for IWS
Valve, torque motor, nitrogen	10	0.375	1000	3.3	33.0	Valving for system interfaces
Valve, check, nitrogen *	4	0.375	200/750	1.5	6.0	Prevention of IWS and experiment backup
Valve, check, nitrogen	12	0.375	1000	1.5	18.0	Check valves for user interfaces
Valve, fill and drain, nitrogen	2	0.375	1000	1.0	2.0	Nitrogen drain or disposal valve
Filter, inline, nitrogen gas	8	0.375	1000	1.0	8.0	Gas delivery purification filters
Regulator, electronic variable w/relief	4	0.375	1000 in, 200/750 out	6.0	24.0	Pressure control, shutoff capability req'd
Regulator, constant pressure w/relief	4	0.375	1000 in, 250 out	3.1	12.4	Pressure control, shutoff capability req'd
Sensor, pressure, nitrogen	2	0.375	250	0.4	0.8	Monitoring of scarred location
Sensor, pressure, nitrogen	6	0.375	1000	0.6	3.6	Compressor output, distribution pressure
Sensor, temperature, nitrogen	4	0.375	250/1000	0.4	1.6	Monitoring of scarred location
Compressor, nitrogen gas	2	0.375	20-250/1000	24.9	49.8	Delivery or combination delivery/transfer
Compressor, nitrogen gas	2	0.375	20-1000	24.9	49.8	Potential for two transfer compressors***
Total Number of Components	120		Total Mass		311.8	lbm***

* Additional hardware required for experiments (quantity currently undetermined)
** Except where units are specified
*** Does not include mass of potential transfer compressors

Table D-10 INS Option 2F Components List (continued)

INS Supply Subsystem Component List - Option 2f

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	1	15.38 cu. ft.	1000	298.0	298.0	Vacuum-jacketed pressure vessel
Valve, vent relief, nitrogen	1	0.375	1000 setpoint	1.5	1.5	Nitrogen tank relief for >1000 psia
Sensor, flowmeter/level, nitrogen	1	0.375	1000	0.8	0.8	Method for cryo-supercritical using P, T
Valve, latching solenoid, nitrogen	4	0.375	1000	2.5	10.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	1	0.375	1000	1.0	1.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	2	0.375	1000	1.0	2.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	3	0.375	1000	0.6	1.8	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	5	0.375	1000	0.4	2.0	Pressure vessel storage monitoring
Pumps, recirculating, nitrogen	2	0.375	1000	20.0	40.0	Recirculator pumps with low head
Heaters, conditioning, nitrogen	4	0.375	1000	3.9	15.6	Heaters for tank and delivery conditioning
Total Number of Components	24		Total Mass		372.7	lbm
Total Supply and Distribution	144				684.5	lbm

* Initial resupply operating pressure
** Except where units are specified

INS Storage Subsystem Component List - Reference System - Option 1

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	848.8 cu. ft.	1000	3259.0	6518.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	1000 setpoint	1.5	3.0	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	1000	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	1000	2.5	20.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	1000	1.0	2.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	1000	1.0	4.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	1000	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	1000	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	1000	0.5	1.0	Low power nitrogen gas tank heater
Total Number of Components	26		Total Mass		6551.6	lbm
GRAND TOTALS	170				7236.1	lbm

* Operating pressure at full condition - the Storage Subsystem study evaluated pressures from 1000 to 8000 psia (shown is 1000 psia Reference System)
** Except where units are specified

Table D-11 INS Option 3 Components List

Configuration 3 - Fully Integrated System - Subcritical Liquid Resupply/Storage

INS Distribution Subsystem Component List - Option 3

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Accumulator, nitrogen surge	2	0.375	1000	20.9	41.8	Located in node berthing locations
Disconnect, halves, nitrogen *	8	0.375	250/750	1.0	8.0	Buildup operations, growth interfaces
Disconnect, halves, nitrogen	18	0.375	1000	1.0	18.0	Buildup operations, growth interfaces
Valve, latching solenoid, nitrogen	2	0.375	250	0.8	1.6	Maximum flowrate = 30 lbm/hr
Valve, latching solenoid, nitrogen	28	0.375	1000	2.5	70.0	Maximum flowrate = 30 lbm/hr
Valve, torque motor, nitrogen *	4	0.375	200/750	3.3	13.2	Interface valving for IWS
Valve, torque motor, nitrogen	10	0.375	1000	3.3	33.0	Valving for system interfaces
Valve, check, nitrogen *	4	0.375	200/750	1.5	6.0	Prevention of IWS and experiment backup
Valve, check, nitrogen	12	0.375	1000	1.5	18.0	Check valves for user interfaces
Valve, fill and drain, nitrogen	2	0.375	1000	1.0	2.0	Nitrogen drain or disposal valve
Filter, inline, nitrogen gas	8	0.375	1000	1.0	8.0	Gas delivery purification filters
Regulator, electronic variable w/relief	4	0.375	1000 in, 200/750 out	6.0	24.0	Pressure control, shutoff capability req'd
Regulator, constant pressure w/relief	4	0.375	1000 in, 250 out	3.1	12.4	Pressure control, shutoff capability req'd
Sensor, pressure, nitrogen	2	0.375	250	0.4	0.8	Monitoring of scarred location
Sensor, pressure, nitrogen	6	0.375	1000	0.6	3.6	Compressor output, distribution pressure
Sensor, temperature, nitrogen	4	0.375	250/1000	0.4	1.6	Monitoring of scarred location
Compressor, nitrogen gas	2	0.375	20-1000	24.9	49.8	Potential for two transfer compressors***
Total Number of Components	118		Total Mass		262.0	lbm***

* Additional hardware required for experiments (quantity currently undetermined)

** Except where units are specified

Table D-11 INS Option 3 Components List (continued)

INS Supply Subsystem Component List - Option 3

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	1	13.65 cu. ft.	20	256.0	256.0	Vacuum-jacketed pressure vessel
Valve, vent relief, nitrogen	1	0.375	20 setpoint	1.5	1.5	Nitrogen tank relief for >20 psia
Sensor, flowmeter/level, nitrogen	1	0.375	20	0.8	0.8	Method for liquid flow or level detection
Valve, latching solenoid, nitrogen	6	0.375	20/1000	2.5	15.0	Tank and distribution system interface
Valve, check, nitrogen	4	0.375	250/1000	1.5	6.0	Prevention of pump and heater backup
Valve, fill and drain, nitrogen	1	0.375	250/1000	1.0	1.0	Nitrogen drain or disposal valve
Regulator, constant pressure w/relief	2	0.375	1000 in, 20 out	3.1	6.2	Autogenous pressurization regulators
Disconnect, halves, nitrogen	2	0.375	250/1000	1.0	2.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	1	0.375	20	0.4	0.4	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	5	0.375	20/1000	0.4	2.0	Pressure vessel storage monitoring
Pumps, positive displ., liquid nitrogen	2	0.375	20-250/1000	22.9	45.8	Delivery or combination delivery/transfer
Heaters, conditioning, nitrogen	2	0.375	250/1000	4.7	9.4	Heaters for tank and delivery conditioning
Total Number of Components	28		Total Mass		346.1	lbm
Total Supply and Distribution	146				608.1	lbm

* Initial resupply operating pressure
** Except where units are specified

INS Storage Subsystem Component List - Reference System - Option 1

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	848.8 cu. ft.	1000	3259.0	6518.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	1000 setpoint	1.5	3.0	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	1000	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	1000	2.5	20.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	1000	1.0	2.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	1000	1.0	4.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	1000	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	1000	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	1000	0.5	1.0	Low power nitrogen gas tank heater
Total Number of Components	26		Total Mass		6551.6	lbm
GRAND TOTALS	172				7159.7	lbm

* Operating pressure at full condition - the Storage Subsystem study evaluated pressures from 1000 to 8000 psia (shown is 1000 psia Reference System)
** Except where units are specified

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Table D-12 INS Option 4A Components List

Configuration 4A - Partially Integrated System - High Pressure Gaseous Resupply/Storage - Racks Dedicated to Experiments

INS Distribution Subsystem Component List - Option 4a

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Accumulator, nitrogen surge	2	0.375	3500	28.4	56.8	Located in node berthing locations
Disconnect, halves, nitrogen *	30	0.375	250/750	1.0	30.0	Buildup operations, growth interfaces
Disconnect, halves, nitrogen	22	0.375	3500	1.0	22.0	Buildup operations, growth interfaces
Valve, latching solenoid, nitrogen	2	0.375	250	0.8	1.6	Maximum flowrate = 24 lbm/hr
Valve, latching solenoid, nitrogen	28	0.375	3500	2.5	70.0	Maximum flowrate = 24 lbm/hr
Valve, torque motor, nitrogen *	26	0.375	200/250/750	3.3	85.8	Interface valving for IWS
Valve, torque motor, nitrogen	12	0.375	3500	3.3	39.6	Valving for system interfaces
Valve, check, nitrogen *	4	0.375	200/750	1.5	6.0	Prevention of IWS and experiment backup
Valve, check, nitrogen	12	0.375	3500	1.5	18.0	Check valves for user interfaces
Valve, fill and drain, nitrogen	2	0.375	3500	1.0	2.0	Nitrogen drain or disposal valve
Filter, inline, nitrogen gas	10	0.375	3500	1.0	10.0	Gas delivery purification filters
Regulator, electronic variable w/relief	4	0.375	3500 in, 200/750 out	6.0	24.0	Pressure control, shutoff capability req'd
Regulator, constant pressure w/relief	6	0.375	3500 in, 250 out	3.1	18.6	Pressure control, shutoff capability req'd
Sensor, pressure, nitrogen	2	0.375	250	0.4	0.8	Monitoring of scarred location
Sensor, pressure, nitrogen	6	0.375	3500	0.6	3.6	Compressor output, distribution pressure
Sensor, temperature, nitrogen	4	0.375	250/3500	0.4	1.6	Monitoring of scarred location
Compressor, nitrogen gas	2	0.375	250-1000	24.9	49.8	Potential for two transfer compressors***
Total Number of Components	172		Total Mass		390.4	lbm***

* Additional hardware required for experiments (quantity currently undetermined)
** Except where units are specified
*** Doesnt' include mass of potential transfer compressors

Table D-12 INS Option 4A Components List (continued)

INS Supply Subsystem Component List - Option 4a

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	1	35.56 cu. ft.	3500	478.0	478.0	Spherical high pressure vessel
Pressure vessel, portable, nitrogen***	5	1.76 cu. ft.	3500	23.6	118.0	Fluids rack dedicated to experiments
Valve, vent relief w/burst disk, nitrogen	1	0.375	3500 setpoint	1.5	1.5	Nitrogen tank relief for >3500 psia
Sensor, gas level, nitrogen	1	0.375	3500	0.8	0.8	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	4	0.375	3500	2.5	10.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	1	0.375	3500	1.0	1.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	3500	1.0	4.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	1	0.375	3500	0.6	0.6	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	1	0.375	3500	0.4	0.4	Pressure vessel storage monitoring
Heater, nitrogen tank	1	TBD	3500	0.5	0.5	Low power nitrogen gas tank heater
Total Number of Components	20		Total Mass		614.8	lbm
Total Supply and Distribution	192				1005.2	lbm

* Initial resupply operating pressure
** Except where units are specified
*** Fluids rack pressure vessels

INS Storage Subsystem Component List - Reference System - Option 1

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	848.8 cu. ft.	1000	3259.0	6518.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	1000 setpoint	1.5	3.0	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	1000	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	1000	2.5	20.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	1000	1.0	2.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	1000	1.0	4.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	1000	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	1000	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	1000	0.5	1.0	Low power nitrogen gas tank heater
Total Number of Components	26		Total Mass		6551.6	lbm
GRAND TOTALS	218				7556.8	lbm

* Operating pressure at full condition - the Storage Subsystem study evaluated pressures from 1000 to 8000 psia (shown is 1000 psia Reference System)
** Except where units are specified

Table D-13 INS Option 4B Components List

Configuration 4B - Partially Integrated System - High Pressure Gaseous Resupply/Storage - Racks Dedicated to Experiments

INS Distribution Subsystem Component List - Option 4b

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Accumulator, nitrogen surge	2	0.375	8000	28.4	56.8	Located in node berthing locations
Disconnect, halves, nitrogen *	30	0.375	250/750	1.0	30.0	Buildup operations, growth interfaces
Disconnect, halves, nitrogen	22	0.375	3500/8000	1.1	24.2	Buildup operations, growth interfaces
Valve, latching solenoid, nitrogen	2	0.375	250	0.8	1.6	Maximum flowrate = 24 lbm/hr
Valve, latching solenoid, nitrogen	28	0.375	8000	2.6	72.8	Maximum flowrate = 24 lbm/hr
Valve, torque motor, nitrogen *	26	0.375	200/250/750	3.3	85.8	Interface valving for IWS
Valve, torque motor, nitrogen	12	0.375	3500/8000	3.3	39.6	Valving for system interfaces
Valve, check, nitrogen *	4	0.375	200/750	1.5	6.0	Prevention of IWS and experiment backup
Valve, check, nitrogen	12	0.375	8000	1.5	18.0	Check valves for user interfaces
Valve, fill and drain, nitrogen	2	0.375	8000	1.1	2.2	Nitrogen drain or disposal valve
Filter, inline, nitrogen gas	10	0.375	8000	1.1	11.0	Gas delivery purification filters
Regulator, electronic variable w/relief	4	0.375	8000 in, 200/750 out	6.0	24.0	Pressure control, shutoff capability req'd
Regulator, constant pressure w/relief	2	0.375	3500 in, 250 out	3.1	6.2	Pressure control, shutoff capability req'd
Regulator, constant pressure w/relief	4	0.375	8000 in, 250 out	3.1	12.4	Pressure control, shutoff capability req'd
Sensor, pressure, nitrogen	2	0.375	250	0.4	0.8	Monitoring of scarred location
Sensor, pressure, nitrogen	6	0.375	8000	0.6	3.6	Compressor output, distribution pressure
Sensor, temperature, nitrogen	4	0.375	250/8000	0.4	1.6	Monitoring of scarred location
Compressor, nitrogen gas	2	0.375	250-1000	24.9	49.8	Potential for two transfer compressors***
Total Number of Components	172		Total Mass		396.6	lbm***

* Additional hardware required for experiments (quantity currently undetermined)
** Except where units are specified
*** Doesnt' include mass of potential transfer compressors

Table D-13 INS Option 4B Components List (continued)

INS Supply Subsystem Component List - Option 4b

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	1	19.32 cu. ft.	8000	594.0	594.0	Spherical high pressure vessel
Pressure vessel, portable, nitrogen***	5	1.76 cu. ft.	3500	23.6	118.0	Fluids rack dedicated to experiments
Valve, vent relief w/burst disk, nitrogen	1	0.375	8000 setpoint	3.9	3.9	Nitrogen tank relief for >8000 psia
Sensor, gas level, nitrogen	1	0.375	8000	0.8	0.8	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	4	0.375	8000	2.6	10.4	Tank and distribution system interface
Valve, fill and drain, nitrogen	1	0.375	8000	1.1	1.1	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	2	0.375	3500	1.0	2.0	Fluids rack supply interface
Disconnect, halves, nitrogen	2	0.375	8000	1.1	2.2	Fluids pallet supply interface
Sensor, pressure, nitrogen	1	0.375	8000	0.6	0.6	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	1	0.375	8000	0.4	0.4	Pressure vessel storage monitoring
Heater, nitrogen tank	1	TBD	8000	0.5	0.5	Low power nitrogen gas tank heater
Total Number of Components	20		Total Mass		733.9	lbm
Total Supply and Distribution	192				1130.5	lbm

* Initial resupply operating pressure
** Except where units are specified
*** Fluids rack pressure vessels

INS Storage Subsystem Component List - Reference System - Option 1

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	848.8 cu. ft.	1000	3259.0	6518.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	1000 setpoint	1.5	3.0	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	1000	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	1000	2.5	20.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	1000	1.0	2.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	1000	1.0	4.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	1000	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	1000	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	1000	0.5	1.0	Low power nitrogen gas tank heater
Total Number of Components	26		Total Mass		6551.6	lbm
GRAND TOTALS	218				7682.1	lbm

* Operating pressure at full condition - the Storage Subsystem study evaluated pressures from 1000 to 8000 psia (shown is 1000 psia Reference System)
** Except where units are specified

Table D-14 INS Option 4C Components List

Configuration 4C - Partially Integrated System - High Pressure Gaseous Resupply/Storage - Racks Dedicated to Experiments

INS Distribution Subsystem Component List - Option 4c

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Accumulator, nitrogen surge	2	0.375	3500	28.4	56.8	Located in node berthing locations
Disconnect, halves, nitrogen *	30	0.375	250/750	1.0	30.0	Buildup operations, growth interfaces
Disconnect, halves, nitrogen	22	0.375	3500	1.0	22.0	Buildup operations, growth interfaces
Valve, latching solenoid, nitrogen	2	0.375	250	0.8	1.6	Maximum flowrate = 24 lbm/hr
Valve, latching solenoid, nitrogen	28	0.375	3500	2.5	70.0	Maximum flowrate = 24 lbm/hr
Valve, torque motor, nitrogen *	26	0.375	200/250/750	3.3	85.8	Interface valving for IWS
Valve, torque motor, nitrogen	12	0.375	3500	3.3	39.6	Valving for system interfaces
Valve, check, nitrogen *	4	0.375	200/750	1.5	6.0	Prevention of IWS and experiment backup
Valve, check, nitrogen	12	0.375	3500	1.5	18.0	Check valves for user interfaces
Valve, fill and drain, nitrogen	2	0.375	3500	1.0	2.0	Nitrogen drain or disposal valve
Filter, inline, nitrogen gas	10	0.375	3500	1.0	10.0	Gas delivery purification filters
Regulator, electronic variable w/relief	4	0.375	3500 in, 200/750 out	6.0	24.0	Pressure control, shutoff capability req'd
Regulator, constant pressure w/relief	6	0.375	3500 in, 250 out	3.1	18.6	Pressure control, shutoff capability req'd
Sensor, pressure, nitrogen	2	0.375	250	0.4	0.8	Monitoring of scarred location
Sensor, pressure, nitrogen	6	0.375	3500	0.6	3.6	Compressor output, distribution pressure
Sensor, temperature, nitrogen	4	0.375	250/3500	0.4	1.6	Monitoring of scarred location
Compressor, nitrogen gas	2	0.375	20-250/1000	24.9	49.8	Delivery or combination delivery/transfer
Compressor, nitrogen gas	2	0.375	20-1000	24.9	49.8	Potential for two transfer compressors***
Total Number of Components	174		Total Mass		440.2	lbm***

* Additional hardware required for experiments (quantity currently undetermined)
** Except where units are specified
*** Doesnt' include mass of potential transfer compressors

Table D-14 INS Option 4C Components List (continued)

INS Supply Subsystem Component List - Option 4c

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	1	32.77 cu. ft.	3500	440.0	440.0	Spherical high pressure vessel
Pressure vessel, portable, nitrogen***	5	1.76 cu. ft.	3500	23.6	118.0	Fluids rack dedicated to experiments
Valve, vent relief w/burst disk, nitrogen	1	0.375	3500 setpoint	1.5	1.5	Nitrogen tank relief for >3500 psia
Sensor, gas level, nitrogen	1	0.375	3500	0.8	0.8	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	4	0.375	3500	2.5	10.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	1	0.375	3500	1.0	1.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	3500	1.0	4.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	1	0.375	3500	0.6	0.6	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	1	0.375	3500	0.4	0.4	Pressure vessel storage monitoring
Heater, nitrogen tank	1	TBD	3500	0.5	0.5	Low power nitrogen gas tank heater
Total Number of Components	20		Total Mass		576.8	lbm
Total Supply and Distribution	194				1017.0	lbm

* Initial resupply operating pressure
** Except where units are specified
*** Fluids rack pressure vessels

INS Storage Subsystem Component List - Reference System - Option 1

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	848.8 cu. ft.	1000	3259.0	6518.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	1000 setpoint	1.5	3.0	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	1000	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	1000	2.5	20.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	1000	1.0	2.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	1000	1.0	4.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	1000	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	1000	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	1000	0.5	1.0	Low power nitrogen gas tank heater
Total Number of Components	26		Total Mass		6551.6	lbm
GRAND TOTALS	220				7568.6	lbm

* Operating pressure at full condition - the Storage Subsystem study evaluated pressures from 1000 to 8000 psia (shown is 1000 psia Reference System)
** Except where units are specified

Table D-15 INS Option 4D Components List

Configuration 4D - Partially Integrated System - High Pressure Gaseous Resupply/Storage - Racks Dedicated to Experiments

INS Distribution Subsystem Component List - Option 4d

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Accumulator, nitrogen surge	2	0.375	8000	28.4	56.8	Located in node berthing locations
Disconnect, halves, nitrogen *	30	0.375	250/750	1.0	30.0	Buildup operations, growth interfaces
Disconnect, halves, nitrogen	22	0.375	3500/8000	1.1	24.2	Buildup operations, growth interfaces
Valve, latching solenoid, nitrogen	2	0.375	250	0.8	1.6	Maximum flowrate = 24 lbm/hr
Valve, latching solenoid, nitrogen	28	0.375	8000	2.6	72.8	Maximum flowrate = 24 lbm/hr
Valve, torque motor, nitrogen *	26	0.375	200/250/750	3.3	85.8	Interface valving for IWS
Valve, torque motor, nitrogen	12	0.375	3500/8000	3.3	39.6	Valving for system interfaces
Valve, check, nitrogen *	4	0.375	200/750	1.5	6.0	Prevention of IWS and experiment backup
Valve, check, nitrogen	12	0.375	8000	1.5	18.0	Check valves for user interfaces
Valve, fill and drain, nitrogen	2	0.375	8000	1.1	2.2	Nitrogen drain or disposal valve
Filter, inline, nitrogen gas	10	0.375	8000	1.1	11.0	Gas delivery purification filters
Regulator, electronic variable w/relief	4	0.375	8000 in, 200/750 out	6.0	24.0	Pressure control, shutoff capability req'd
Regulator, constant pressure w/relief	2	0.375	3500 in, 250 out	3.1	6.2	Pressure control, shutoff capability req'd
Regulator, constant pressure w/relief	4	0.375	8000 in, 250 out	3.1	12.4	Pressure control, shutoff capability req'd
Sensor, pressure, nitrogen	2	0.375	250	0.4	0.8	Monitoring of scarred location
Sensor, pressure, nitrogen	6	0.375	8000	0.6	3.6	Compressor output, distribution pressure
Sensor, temperature, nitrogen	4	0.375	250/8000	0.4	1.6	Monitoring of scarred location
Compressor, nitrogen gas	2	0.375	20-250/1000	24.9	49.8	Delivery or combination delivery/transfer
Compressor, nitrogen gas	2	0.375	20-1000	24.9	49.8	Potential for two transfer compressors***
Total Number of Components	174		Total Mass		446.4	lbm***

* Additional hardware required for experiments (quantity currently undetermined)
** Except where units are specified
*** Doesnt' include mass of potential transfer compressors

Table D-15 INS Option 4D Components List (continued)

INS Supply Subsystem Component List - Option 4d

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	1	18.46 cu. ft.	8000	567.0	567.0	Spherical high pressure vessel
Pressure vessel, portable, nitrogen	5	1.76 cu. ft.	3500	23.6	118.0	Fluids rack dedicated to experiments
Valve, vent relief w/burst disk, nitrogen	1	0.375	8000 setpoint	3.9	3.9	Nitrogen tank relief for >8000 psia
Sensor, gas level, nitrogen	1	0.375	8000	0.8	0.8	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	4	0.375	8000	2.6	10.4	Tank and distribution system interface
Valve, fill and drain, nitrogen	1	0.375	8000	1.1	1.1	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	2	0.375	3500	1.0	2.0	Fluids rack supply interface
Disconnect, halves, nitrogen	2	0.375	8000	1.1	2.2	Fluids pallet supply interface
Sensor, pressure, nitrogen	1	0.375	8000	0.6	0.6	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	1	0.375	8000	0.4	0.4	Pressure vessel storage monitoring
Heater, nitrogen tank	1	TBD	8000	0.5	0.5	Low power nitrogen gas tank heater
Total Number of Components	20		Total Mass		706.9	lbm
Total Supply and Distribution	194				1153.3	lbm

* Initial resupply operating pressure
** Except where units are specified
*** Fluids rack pressure vessels

INS Storage Subsystem Component List - Reference System - Option 1

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	848.8 cu. ft.	1000	3259.0	6518.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	1000 setpoint	1.5	3.0	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	1000	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	1000	2.5	20.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	1000	1.0	2.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	1000	1.0	4.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	1000	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	1000	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	1000	0.5	1.0	Low power nitrogen gas tank heater
Total Number of Components	26		Total Mass		6551.6	lbm
GRAND TOTALS	220				7704.9	lbm

* Operating pressure at full condition - the Storage Subsystem study evaluated pressures from 1000 to 8000 psia (shown is 1000 psia Reference System)
** Except where units are specified

Table D-16 INS Option 4E Components List

Configuration 4E - Partially Integrated System - High Pressure Gaseous Resupply/Storage - Racks Dedicated to Experiments

INS Distribution Subsystem Component List - Option 4e

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Accumulator, nitrogen surge	2	0.375	3500	28.4	56.8	Located in node berthing locations
Disconnect, halves, nitrogen *	8	0.375	250/750	1.0	8.0	Buildup operations, growth interfaces
Disconnect, halves, nitrogen	30	0.375	3500	1.0	30.0	Buildup operations, growth interfaces
Valve, latching solenoid, nitrogen	2	0.375	250	0.8	1.6	Maximum flowrate = 24 lbm/hr
Valve, latching solenoid, nitrogen	28	0.375	3500	2.5	70.0	Maximum flowrate = 24 lbm/hr
Valve, torque motor, nitrogen *	4	0.375	200/250/750	3.3	13.2	Interface valving for IWS
Valve, torque motor, nitrogen	16	0.375	3500	3.3	52.8	Valving for system interfaces
Valve, check, nitrogen *	4	0.375	200/750	1.5	6.0	Prevention of IWS and experiment backup
Valve, check, nitrogen	12	0.375	3500	1.5	18.0	Check valves for user interfaces
Valve, fill and drain, nitrogen	2	0.375	3500	1.0	2.0	Nitrogen drain or disposal valve
Filter, inline, nitrogen gas	14	0.375	3500	1.0	14.0	Gas delivery purification filters
Regulator, electronic variable w/relief	4	0.375	3500 in, 200/750 out	6.0	24.0	Pressure control, shutoff capability req'd
Regulator, constant pressure w/relief	10	0.375	3500 in, 250 out	3.1	31.0	Pressure control, shutoff capability req'd
Sensor, pressure, nitrogen	2	0.375	250	0.4	0.8	Monitoring of scarred location
Sensor, pressure, nitrogen	6	0.375	3500	0.6	3.6	Compressor output, distribution pressure
Sensor, temperature, nitrogen	4	0.375	250/3500	0.4	1.6	Monitoring of scarred location
Compressor, nitrogen gas	2	0.375	250-1000	24.9	49.8	Potential for two transfer compressors***
Total Number of Components	148		Total Mass		333.4	lbm***

* Additional hardware required for experiments (quantity currently undetermined)
** Except where units are specified
*** Doesnt' include mass of potential transfer compressors

Table D-16 INS Option 4E Components List (continued)

INS Supply Subsystem Component List - Option 4e

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	1	35.56 cu. ft.	3500	478.0	478.0	Spherical high pressure vessel
Pressure vessel, portable, nitrogen***	5	1.76 cu. ft.	3500	23.6	118.0	Fluids rack dedicated to experiments
Valve, vent relief w/burst disk, nitrogen	1	0.375	3500 setpoint	1.5	1.5	Nitrogen tank relief for >3500 psia
Sensor, gas level, nitrogen	1	0.375	3500	0.8	0.8	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	4	0.375	3500	2.5	10.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	1	0.375	3500	1.0	1.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	8	0.375	3500	1.0	8.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	1	0.375	3500	0.6	0.6	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	1	0.375	3500	0.4	0.4	Pressure vessel storage monitoring
Heater, nitrogen tank	1	TBD	3500	0.5	0.5	Low power nitrogen gas tank heater
Total Number of Components	24		Total Mass		618.8	lbm
Total Supply and Distribution	172				952.2	lbm

* Initial resupply operating pressure
** Except where units are specified
*** Fluids rack pressure vessels

INS Storage Subsystem Component List - Reference System - Option 1

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	848.8 cu. ft.	1000	3259.0	6518.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	1000 setpoint	1.5	3.0	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	1000	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	1000	2.5	20.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	1000	1.0	2.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	1000	1.0	4.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	1000	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	1000	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	1000	0.5	1.0	Low power nitrogen gas tank heater
Total Number of Components	26		Total Mass		6551.6	lbm
GRAND TOTALS	198				7503.8	lbm

* Operating pressure at full condition - the Storage Subsystem study evaluated pressures from 1000 to 8000 psia (shown is 1000 psia Reference System)
** Except where units are specified

Table D-17 INS Option 4F Components List

Configuration 4F - Partially Integrated System - High Pressure Gaseous Resupply/Storage - Racks Dedicated to Experiments

INS Distribution Subsystem Component List - Option 4f

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Accumulator, nitrogen surge	2	0.375	8000	28.4	56.8	Located in node berthing locations
Disconnect, halves, nitrogen *	8	0.375	250/750	1.0	8.0	Buildup operations, growth interfaces
Disconnect, halves, nitrogen	30	0.375	3500/8000	1.1	33.0	Buildup operations, growth interfaces
Valve, latching solenoid, nitrogen	2	0.375	250	0.8	1.6	Maximum flowrate = 24 lbm/hr
Valve, latching solenoid, nitrogen	28	0.375	8000	2.6	72.8	Maximum flowrate = 24 lbm/hr
Valve, torque motor, nitrogen *	4	0.375	200/250/750	3.3	13.2	Interface valving for IWS
Valve, torque motor, nitrogen	16	0.375	3500/8000	3.3	52.8	Valving for system interfaces
Valve, check, nitrogen *	4	0.375	200/750	1.5	6.0	Prevention of IWS and experiment backup
Valve, check, nitrogen	12	0.375	8000	1.5	18.0	Check valves for user interfaces
Valve, fill and drain, nitrogen	2	0.375	8000	1.1	2.2	Nitrogen drain or disposal valve
Filter, inline, nitrogen gas	14	0.375	8000	1.1	15.4	Gas delivery purification filters
Regulator, electronic variable w/relief	4	0.375	8000 in, 200/750 out	6.0	24.0	Pressure control, shutoff capability req'd
Regulator, constant pressure w/relief	6	0.375	3500 in, 250 out	3.1	18.6	Pressure control, shutoff capability req'd
Regulator, constant pressure w/relief	4	0.375	8000 in, 250 out	3.1	12.4	Pressure control, shutoff capability req'd
Sensor, pressure, nitrogen	2	0.375	250	0.4	0.8	Monitoring of scarred location
Sensor, pressure, nitrogen	6	0.375	8000	0.6	3.6	Compressor output, distribution pressure
Sensor, temperature, nitrogen	4	0.375	250/8000	0.4	1.6	Monitoring of scarred location
Compressor, nitrogen gas	2	0.375	250-1000	24.9	49.8	Potential for two transfer compressors***
Total Number of Components	148		Total Mass		340.8	lbm***

* Additional hardware required for experiments (quantity currently undetermined)
** Except where units are specified
*** Doesnt' include mass of potential transfer compressors

Table D-17 INS Option 4F Components List (continued)

INS Supply Subsystem Component List - Option 4f

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	1	19.32 cu. ft.	8000	594.0	594.0	Spherical high pressure vessel
Pressure vessel, portable, nitrogen***	5	1.76 cu. ft.	3500	23.6	118.0	Fluids rack dedicated to experiments
Valve, vent relief w/burst disk, nitrogen	1	0.375	8000 setpoint	3.9	3.9	Nitrogen tank relief for >8000 psia
Sensor, gas level, nitrogen	1	0.375	8000	0.8	0.8	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	4	0.375	8000	2.6	10.4	Tank and distribution system interface
Valve, fill and drain, nitrogen	1	0.375	8000	1.1	1.1	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	6	0.375	3500	1.0	6.0	Fluids rack supply interface
Disconnect, halves, nitrogen	2	0.375	8000	1.1	2.2	Fluids pallet supply interface
Sensor, pressure, nitrogen	1	0.375	8000	0.6	0.6	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	1	0.375	8000	0.4	0.4	Pressure vessel storage monitoring
Heater, nitrogen tank	1	TBD	8000	0.5	0.5	Low power nitrogen gas tank heater
Total Number of Components	24		Total Mass		737.9	lbm
Total Supply and Distribution	172				1078.7	lbm

* Initial resupply operating pressure
** Except where units are specified
*** Fluids rack pressure vessels

INS Storage Subsystem Component List - Reference System - Option 1

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	848.8 cu. ft.	1000	3259.0	6518.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	1000 setpoint	1.5	3.0	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	1000	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	1000	2.5	20.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	1000	1.0	2.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	1000	1.0	4.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	1000	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	1000	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	1000	0.5	1.0	Low power nitrogen gas tank heater
Total Number of Components	26		Total Mass		6551.6	lbm
GRAND TOTALS	198				7630.3	lbm

* Operating pressure at full condition - the Storage Subsystem study evaluated pressures from 1000 to 8000 psia (shown is 1000 psia Reference System)
** Except where units are specified

Table D-18 INS Option 4G Components List

Configuration 4G - Partially Integrated System - High Pressure Gaseous Resupply/Storage - Racks Dedicated to Experiments

INS Distribution Subsystem Component List - Option 4g

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Accumulator, nitrogen surge	2	0.375	3500	28.4	56.8	Located in node berthing locations
Disconnect, halves, nitrogen *	8	0.375	250/750	1.0	8.0	Buildup operations, growth interfaces
Disconnect, halves, nitrogen	30	0.375	3500	1.0	30.0	Buildup operations, growth interfaces
Valve, latching solenoid, nitrogen	2	0.375	250	0.8	1.6	Maximum flowrate = 24 lbm/hr
Valve, latching solenoid, nitrogen	28	0.375	3500	2.5	70.0	Maximum flowrate = 24 lbm/hr
Valve, torque motor, nitrogen *	4	0.375	200/250/750	3.3	13.2	Interface valving for IWS
Valve, torque motor, nitrogen	16	0.375	3500	3.3	52.8	Valving for system interfaces
Valve, check, nitrogen *	4	0.375	200/750	1.5	6.0	Prevention of IWS and experiment backup
Valve, check, nitrogen	12	0.375	3500	1.5	18.0	Check valves for user interfaces
Valve, fill and drain, nitrogen	2	0.375	3500	1.0	2.0	Nitrogen drain or disposal valve
Filter, inline, nitrogen gas	14	0.375	3500	1.0	14.0	Gas delivery purification filters
Regulator, electronic variable w/relief	4	0.375	3500 in, 200/750 out	6.0	24.0	Pressure control, shutoff capability req'd
Regulator, constant pressure w/relief	10	0.375	3500 in, 250 out	3.1	31.0	Pressure control, shutoff capability req'd
Sensor, pressure, nitrogen	2	0.375	250	0.4	0.8	Monitoring of scarred location
Sensor, pressure, nitrogen	6	0.375	3500	0.6	3.6	Compressor output, distribution pressure
Sensor, temperature, nitrogen	4	0.375	250/3500	0.4	1.6	Monitoring of scarred location
Compressor, nitrogen gas	2	0.375	20-250/1000	24.9	49.8	Delivery or combination delivery/transfer
Compressor, nitrogen gas	2	0.375	20-1000	24.9	49.8	Potential for two transfer compressors***
Total Number of Components	150		Total Mass		383.2	lbm***

* Additional hardware required for experiments (quantity currently undetermined)
** Except where units are specified
*** Doesnt' include mass of potential transfer compressors

Table D-18 INS Option 4G Components List (continued)

INS Supply Subsystem Component List - Option 4g

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	1	32.77 cu. ft.	3500	440.0	440.0	Spherical high pressure vessel
Pressure vessel, portable, nitrogen***	5	1.76 cu. ft.	3500	23.6	118.0	Fluids rack dedicated to experiments
Valve, vent relief w/burst disk, nitrogen	1	0.375	3500 setpoint	1.5	1.5	Nitrogen tank relief for >3500 psia
Sensor, gas level, nitrogen	1	0.375	3500	0.8	0.8	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	4	0.375	3500	2.5	10.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	1	0.375	3500	1.0	1.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	8	0.375	3500	1.0	8.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	1	0.375	3500	0.6	0.6	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	1	0.375	3500	0.4	0.4	Pressure vessel storage monitoring
Heater, nitrogen tank	1	TBD	3500	0.5	0.5	Low power nitrogen gas tank heater
Total Number of Components	24		Total Mass		580.8	lbm
Total Supply and Distribution	174				964	lbm

* Initial resupply operating pressure
** Except where units are specified
*** Fluids rack pressure vessels

INS Storage Subsystem Component List - Reference System - Option 1

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	848.8 cu. ft.	1000	3259.0	6518.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	1000 setpoint	1.5	3.0	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	1000	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	1000	2.5	20.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	1000	1.0	2.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	1000	1.0	4.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	1000	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	1000	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	1000	0.5	1.0	Low power nitrogen gas tank heater
Total Number of Components	26		Total Mass		6551.6	lbm
GRAND TOTALS	200				7515.6	lbm

* Operating pressure at full condition - the Storage Subsystem study evaluated pressures from 1000 to 8000 psia (shown is 1000 psia Reference System)
** Except where units are specified

Table D-19 INS Option 4H Components List

Configuration 4H - Partially Integrated System - High Pressure Gaseous Resupply/Storage - Racks Dedicated to Experiments

INS Distribution Subsystem Component List - Option 4h

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Accumulator, nitrogen surge	2	0.375	8000	28.4	56.8	Located in node berthing locations
Disconnect, halves, nitrogen *	8	0.375	250/750	1.0	8.0	Buildup operations, growth interfaces
Disconnect, halves, nitrogen	30	0.375	3500/8000	1.1	33.0	Buildup operations, growth interfaces
Valve, latching solenoid, nitrogen	2	0.375	250	0.8	1.6	Maximum flowrate = 24 lbm/hr
Valve, latching solenoid, nitrogen	28	0.375	8000	2.6	72.8	Maximum flowrate = 24 lbm/hr
Valve, torque motor, nitrogen *	4	0.375	200/250/750	3.3	13.2	Interface valving for IWS
Valve, torque motor, nitrogen	16	0.375	3500/8000	3.3	52.8	Valving for system interfaces
Valve, check, nitrogen *	4	0.375	200/750	1.5	6.0	Prevention of IWS and experiment backup
Valve, check, nitrogen	12	0.375	8000	1.5	18.0	Check valves for user interfaces
Valve, fill and drain, nitrogen	2	0.375	8000	1.1	2.2	Nitrogen drain or disposal valve
Filter, inline, nitrogen gas	14	0.375	8000	1.1	15.4	Gas delivery purification filters
Regulator, electronic variable w/relief	4	0.375	8000 in, 200/750 out	6.0	24.0	Pressure control, shutoff capability req'd
Regulator, constant pressure w/relief	6	0.375	3500 in, 250 out	3.1	18.6	Pressure control, shutoff capability req'd
Regulator, constant pressure w/relief	4	0.375	8000 in, 250 out	3.1	12.4	Pressure control, shutoff capability req'd
Sensor, pressure, nitrogen	2	0.375	250	0.4	0.8	Monitoring of scarred location
Sensor, pressure, nitrogen	6	0.375	3500	0.6	3.6	Compressor output, distribution pressure
Sensor, temperature, nitrogen	4	0.375	250/3500	0.4	1.6	Monitoring of scarred location
Compressor, nitrogen gas	2	0.375	20-250/1000	24.9	49.8	Delivery or combination delivery/transfer
Compressor, nitrogen gas	2	0.375	20-1000	24.9	49.8	Potential for two transfer compressors***
Total Number of Components	150		Total Mass		390.6	lbm***

* Additional hardware required for experiments (quantity currently undetermined)

** Except where units are specified

*** Doesnt' include mass of potential transfer compressors

Table D-19 INS Option 4H Components List (continued)

INS Supply Subsystem Component List - Option 4h

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	1	18.46 cu. ft.	8000	567.0	567.0	Spherical high pressure vessel
Pressure vessel, portable, nitrogen***	5	1.76 cu. ft.	3500	23.6	118.0	Fluids rack dedicated to experiments
Valve, vent relief w/burst disk, nitrogen	1	0.375	8000 setpoint	3.9	3.9	Nitrogen tank relief for >8000 psia
Sensor, gas level, nitrogen	1	0.375	8000	0.8	0.8	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	4	0.375	8000	2.6	10.4	Tank and distribution system interface
Valve, fill and drain, nitrogen	1	0.375	8000	1.1	1.1	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	6	0.375	3500	1.0	6.0	Fluids rack supply interface
Disconnect, halves, nitrogen	2	0.375	8000	1.1	2.2	Fluids pallet supply interface
Sensor, pressure, nitrogen	1	0.375	8000	0.6	0.6	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	1	0.375	8000	0.4	0.4	Pressure vessel storage monitoring
Heater, nitrogen tank	1	TBD	8000	0.5	0.5	Low power nitrogen gas tank heater
Total Number of Components	24		Total Mass		710.9	lbm
Total Supply and Distribution	174				1101.5	lbm

* Initial resupply operating pressure
** Except where units are specified
*** Fluids rack pressure vessels

INS Storage Subsystem Component List - Reference System - Option 1

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia) *	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	848.8 cu. ft.	1000	3259.0	6518.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	1000 setpoint	1.5	3.0	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	1000	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	1000	2.5	20.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	1000	1.0	2.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	1000	1.0	4.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	1000	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	1000	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	1000	0.5	1.0	Low power nitrogen gas tank heater
Total Number of Components	26		Total Mass		6551.6	lbm
GRAND TOTALS	200				7653.1	lbm

* Operating pressure at full condition - the Storage Subsystem study evaluated pressures from 1000 to 8000 psia (shown is 1000 psia Reference System)
** Except where units are specified

Table D-20 INS Contingency Storage Subsystem Options at 1,000 and 1,500 psia

INS Storage Subsystem Component List - Reference System - Option 1

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)*	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	848.8 cu. ft.	1000	3259.0	6518.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	1000 setpoint	1.5	3.0	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	1000	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	1000	2.5	20.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	1000	1.0	2.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	1000	1.0	4.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	1000	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	1000	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	1000	0.5	1.0	Low power nitrogen gas tank heater

Total Components	26	Total Mass	6551.6	lbm

* Operating pressure at full condition

** Except where units are specified

INS Storage Subsystem Component List - Alternate System - Option 2

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)*	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	282.3 cu. ft.	1500	1626.0	3252.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	1500 setpoint	1.5	3.0	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	1500	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	1500	2.5	20.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	1500	1.0	2.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	1500	1.0	4.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	1500	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	1500	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	1500	0.5	1.0	Low power nitrogen gas tank heater

Total Components	26	Total Mass	3285.6	lbm

* Operating pressure at full condition

** Except where units are specified

Table D-21 INS Contingency Storage Subsystem Options at 2,000 and 3,000 psia

INS Storage Subsystem Component List - Alternate System - Option 3

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)*	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	168.4 cu. ft.	2000	1293.0	2586.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	2000 setpoint	1.5	3.0	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	2000	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	2000	2.5	20.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	2000	1.0	2.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	2000	1.0	4.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	2000	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	2000	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	2000	0.5	1.0	Low power nitrogen gas tank heater

Total Components	26	Total Mass	2619.6	lbm

* Operating pressure at full condition
** Except where units are specified

INS Storage Subsystem Component List - Alternate System - Option 4

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)*	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	98.05	3000	1130.0	2260.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	3000 setpoint	1.5	3.0	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	3000	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	3000	2.5	20.0	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	3000	1.0	2.0	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	3000	1.0	4.0	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	3000	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	3000	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	3000	0.5	1.0	Low power nitrogen gas tank heater

Total Mass	26	Total Mass	2293.6	lbm

* Operating pressure at full condition
** Except where units are specified

Table D-22 INS Contingency Storage Subsystem Options at 4,000 and 5,000 psia

INS Storage Subsystem Component List - Alternate System - Option 5

Item*	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)*	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	71.69	4000	1101.0	2202.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	4000 setpoint	3.9	7.8	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	4000	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	4000	2.6	20.8	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	4000	1.1	2.2	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	4000	1.1	4.4	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	4000	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	4000	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	4000	0.5	1.0	Low power nitrogen gas tank heater

Total Components	26	Total Mass	2241.8	lbm

* Operating pressure at full condition
** Except where units are specified

INS Storage Subsystem Component List - Alternate System - Option 6

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)*	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	58.45	5000	1122.0	2244.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	5000 setpoint	3.9	7.8	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	5000	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	5000	2.6	20.8	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	5000	1.1	2.2	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	5000	1.1	4.4	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	5000	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	5000	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	5000	0.5	1.0	Low power nitrogen gas tank heater

Total Components	26	Total Mass	2283.8	lbm

* Operating pressure at full condition
** Except where units are specified

Table D-23 INS Contingency Storage Subsystem Options at 6,000 and 7,000 psia

INS Storage Subsystem Component List - Alternate System - Option 7

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)*	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	50.61	6000	1166.0	2332.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	6000 setpoint	3.9	7.8	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	6000	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	6000	2.6	20.8	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	6000	1.1	2.2	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	6000	1.1	4.4	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	6000	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	6000	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	6000	0.5	1.0	Low power nitrogen gas tank heater

Total Components	26	Total Mass	2371.8	lbm

* Operating pressure at full condition
** Except where units are specified

INS Storage Subsystem Component List - Alternate System - Option 8

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)*	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	46.01	7000	1237.0	2474.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	7000 setpoint	3.9	7.8	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	7000	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	7000	2.6	20.8	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	7000	1.1	2.2	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	7000	1.1	4.4	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	7000	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	7000	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	7000	0.5	1.0	Low power nitrogen gas tank heater

Total Components	26	Total Mass	2513.8	lbm

* Operating pressure at full condition
** Except where units are specified

Table D-24 INS Contingency Storage Subsystem Option at 8,000 psia

INS Storage Subsystem Component List - Alternate System - Option 9

Item	Qty., IOC	Size (in)**	Pressure (MEOP) (psia)*	Mass/Item (lbm)	Total Mass (lbm)	Remarks
Pressure vessel, nitrogen	2	41.53	8000	1276.0	2552.0	Spherical high pressure vessel
Valve, vent relief w/burst disk, nitrogen	2	0.375	8000 setpoint	3.9	7.8	Nitrogen tank relief for operating pressure
Sensor, gas level, nitrogen	2	0.375	8000	0.8	1.6	Ideal gas, PV/RT quantity measurement
Valve, latching solenoid, nitrogen	8	0.375	8000	2.6	20.8	Tank and distribution system interface
Valve, fill and drain, nitrogen	2	0.375	8000	1.1	2.2	Nitrogen drain or disposal valve
Disconnect, halves, nitrogen	4	0.375	8000	1.1	4.4	Supply/distribution subsystem interface
Sensor, pressure, nitrogen	2	0.375	8000	0.6	1.2	Pressure vessel storage monitoring
Sensor, temperature, nitrogen	2	0.375	8000	0.4	0.8	Pressure vessel storage monitoring
Heater, nitrogen tank	2	TBD	8000	0.5	1.0	Low power nitrogen gas tank heater
Total Components	26		Total Mass		2591.8	lbm

* Operating pressure at full condition

** Except where units are specified

APPENDIX E

Baseline Experiments

This appendix contains Tables E-1 through E-14 and defines the quantities of chemicals to be used in typical US Laboratory experiments. These experiments were used as the baseline for the Integrated Waste Fluid Management System.

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Table E-1 Acoustic Containerless Processing Experiment

EXPERIMENT : ACOUSTIC CONTAINERLESS PROCESSING

PURPOSE : PROCESS HIGH QUALITY FLUORIDE GLASS BY ACOUSTIC LEVITATION AND MONITORS PROCESS PARAMETERS INCLUDING TEMPERATURE AND ACOUSTIC FIELD PROPERTIES

CYCLES: 7 PER 90 DAYS

EXPERIMENT FACILITIES	CONSTITUENTS IN FACILITY	PHASE	HAZARDS	CONSTITUENT TYPE	MASS VENTED PER CYCLE (LBM)	VOLUME VENTED PER CYCLE (CU IN.)	VENT RATE (CU.IN./MIN)	FINAL VENT PRESSURE (TORR)	COMMENTS
ACOUSTIC LEVITATOR	HELIUM	G		I	0.002	244.095		0.001	USED FOR RAPID SAMPLE QUENCH
	ARGON	G		I	1.162	25019.742	13425.227	0.001	MAY BE HE,AR OR XE DEPENDING ON MATERIAL
	AIR	G		I,O	0.116	2501.974		0.001	USED TO FILL FACILITY AFTER RUN
	XENON	G		I				0.001	
	MELT VAPORS	G				0.000		0.001	
	FLUORIDE GLASS		T	I					
	ALUMINA			I					
	BOULE FRAGMENTS	P			0.000	0.000			
	FLUORIDE GLASS		T	I					
	ALUMINA			I					
	CLEANING FLUIDS	L,G			0.044	1.220		760	USED TO CLEAN CONTAINER WALLS; (0.1 L RUN CONSUMED)
	DISTILLED WATER			I	0.004	0.122		760	USED FOR FACILITY CLEAN-UP; (1.0 L/RUN CONSUMED)
	METHANOL		T	F					
FLUIDS GLOVEBOX	NITROGEN	G		I	0.409	9153.564		760	THIS WILL BE RECYCLED BETWEEN RUNS
	CLEANING FLUIDS	L,G	T	I,F	0.022			760	
AUTOMATED CUTTING/POLISHING	CUT/POLISH SOLUTION	L	PT	F	0.000	0.003		760	
	(WATER/OIL COMBINATION)								
	CLEANING FLUIDS	L	T	I,F	0.022			760	
	DISTILLED WATER	L		I	0.001	0.031		760	
	BOULE FRAGMENTS	P						760	
	FLUORIDE GLASS		I	I					
	ALUMINA			I					
	ENCAPSULANT MATERIAL	P	PT	F	0.0000143	0.0003051		760	
DIFFERENTIAL SCANNING	NITROGEN	G		I	0.008	183.071		0.001	6 L/OF ONE GAS PER RUN; N2 USED 1/2 TIME
CALORIMETER	OXYGEN	G	F,T	O	0.003	61.024		0.001	6 L/OF ONE GAS PER RUN; O2 USED 1/6 TIME
	HYDROGEN	G	F,T	F	0.000	61.024		0.001	6 L/OF ONE GAS PER RUN; H2 USED 1/6 TIME
	ARGON	G		I	0.004	61.024		0.001	6 L/OF ONE GAS PER RUN; AR USED 1/6 TIME
	NITROGEN	L	K	I	0.888	30.512		0.001	
	AIR	G		I,O					
SCANNING ELECTRON MICROSCOPE	NITROGEN	L		I	3.554	122.048		0.000005	PER HOUR USE FOR COLD TRAP (USED FOR 1 HR IN EXPER.)
	ARGON	G		I	0.111	1726.972		0.00001	VACUUM TO 1E-6 AND BACKFILL WITH ARGON GAS TO
									1E-4 TO 1E-3 TORR.
SPUTTERING DEPOSITION UNIT	ARGON	G		I	0.111	1726.972		0.000001	28.3 LITERS OF ARGON ARE CONSUMED (ASSUMED FROM
	AIR	G		I,O					CONSUMEABLES TABLE)
	TRACE VAPORS	G	PT	F					TRACE VAPORS OF FLUORIDE GLASS AND ALUMINA

HAZARDS
T - TOXIC
F - FLAMMABLE
C - CORROSIVE
PT - POSSIBLY TOXIC
PF - POSSIBLY FLAMMABLE
K - COLD

CONSTITUENT TYPE
O - OXIDIZER
F - FUEL
A - ACID
B - BASE
I - INERT

Table E-2 Continuous Flow Electrophoresis Experiment

EXPERIMENT : CONTINUOUS FLOW ELECTROPHORESIS

PURPOSE : SEPARATES SPECIFIC CELLS FROM A BATCH OF RAW MATERIALS BY CONTINUOUS FLOW ELECTROPHORESIS AND MONITORS CONTROL PARAMETERS, INCLUDING FLOW RATE, TEMPERATURE AND FIELD STRENGTH

CYCLES: 8 PER 90 DAYS

EXPERIMENT FACILITIES	CONSTITUENT VENTED	PHASE	HAZARDS	CONTITUENT TYPE	MASS VENTED PER CYCLE (LBM)	VOLUME VENTED PER CYCLE (CU. IN.)	VENT RATE (CU.IN./MIN)	FINAL VENT PRESSURE (TORR)	COMMENTS
CONTINUOUS FLOW ELECTROPHORESIS	DEION/DEPYRO WATER	L			0.309	8.543		760	PURE; ALLOWS NO MICROBIAL GROWTH
	CULTURE MEDIUM	L			0.000	0.000		760	
	BUFFER SOLUTION	L,P	C		0.008	0.165		760	CONCENTRATED; WILL BE MIXED WITH WATER TO FORM A 2% SOLUTION
	1-2% PHOSPHATE								
	BORATE, BARBITOL								
	IN WATER								
	DISINFECTANTS	L,G	T			0.153		760	COULD BE EITHER SODIUM AZ. OR GLUTER.
	GLUTERALDEHYDE								
	SODIUM AZIDE								
	STAINING FLUID	L				0.000		760	
	RAW MATERIAL	L,P				0.000		760	COULD BE CELLS, PROTEINS, HORMONES, ENZYMES OR OTHER BIOLOGICAL MATERIA SEMISOLID OR GEL IN PRERUN STATE
INCUBATOR	CARBON DIOXIDE	G							
	OXYGEN	G	T,F	O					
	AIR	G		I,O		6102.376		760	VENT TO MAINTAIN 1 ATMOSHPHERE
	CULTURE MEDIA	L		F					
	NUTRIENTS	L		F					
FLUIDS GLOVEBOX	NITROGEN	G		I		9153.564		760	THIS WILL BE RECYCLED FOR FREQUENT USE
	SEMISOLID OR GEL	L,P		F					
	BUFFER SOLUTION	L							
	SODIUM AZIDE	L							
	GLUTERALDEHYDE	L							
	STAINING FLUID	L							
	OUTPUT SAMPLES	L				6.102			
						0.610			
HIGH PERFORMANCE LIQUID CHROMATOGRAPH	DISTILLED WATER	L			0.001	0.031		760	USED WITH METHONAL AND ACETONITRILE IN MOBILE PHASE IN VARYING AMOUNTS
	ACETONITRILE	L	PF,PT		0.002	122.048		760	USED WITH WATER IN VARYING AMOUNTS
	DISINFECTANTS	L	T			0.305		760	USED WITH WATER IN VARYING AMOUNTS
	METHONAL	L	PF,PT	F		1.220		760	USED WITH WATER IN VARYING AMOUNTS
STEAM AUTOCLAVE	NITROGEN	L		I					
	DISTILLED WATER	L,G				0.015		760	EXPECT TO USE ONCE PER DAY
	AIR	G		I,O					

HAZARDS
T = TOXIC
F = FLAMMABLE
C = CORROSIVE
PT = POSSIBLY TOXIC
PF = POSSIBLY FLAMMABLE
K = COLD

CONSTITUENT TYPE
O = OXIDIZER
F = FUEL
A = ACID
B = BASE
I = INERT

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Table E-3 Directional Solidification Experiment

EXPERIMENT : DIRECTIONAL SOLIDIFICATION

PURPOSE : GROWS BULK QUANTITIES OF SINGLE CRYSTAL MERCURY- CADMIUM-TELLURIDE FROM A MELT BY A DIRECTIONAL SOLIDIFICATION PROCESS

CYCLES: 5 PER 90 DAYS.

EXPERIMENT FACILITIES	CONSTITUENTS IN FACILITY	PHASE	HAZARDS	CONSTITUENT TYPE	MASS VENTED PER CYCLE (LBM)	VOLUME VENTED PER CYCLE (CU IN.)	VENT RATE (CU.IN./MIN)	FINAL VENT PRESSURE (TORR)	COMMENTS
SMALL BRIDGE FACILITY	ARGON	G		I	0.687	19.008		0.001	AN INERT GAS IS REQUIRED, FILLS ENCLOSURE
	AIR	G	SC	I,O	0.494	13.669		0.001	USED TO REFILL FACILITY AFTER RUN
	CLEANING FLUIDS				0.011	0.305		760	
	DISTILLED WATER	L,G		I	0.004	0.122		760	QUANTITIES NOT DEFINED
	WEAK ACIDS	L,G	PT	I,O	TBD	TBD		760	UNDEFINED
	CONTAINED CONTAMINANTS	G			0.000	0.002		760	QUANTITIES NOT DEFINED
	MERCURY	L,G	T	F					
	CADMIUM	P,G	T	F					
	TELLURIUM	P	PT	F					
	BERYLLIUM	P	T	F					
	COPPER	P	PT	F					
	(AMPOULE BREAKAGE ONLY)	P	I	I	0.000	0.000		760	MOST LIKELY TO BE GLASS
FLUIDS GLOVEBOX	NITROGEN	G		I	11.442	11.442		760	RECYCLE BETWEEN RESUPPLIES
	CLEANING FLUIDS								
	WATER	L,G		I					
	WEAK ACIDS	L,G	PT	I,O	TBD	TBD		760	
	ETCHANTS								QUANTITIES UNDEFINED
	HYDROFLUORIC ACID	L,G	C	O					UNDEFINED CONCENTRATION
	METHANOL	L,G	T,F	F					
	NITRIC ACID	L,G	C	O					UNDEFINED CONCENTRATION
	HYDROCHLORIC ACID	L,G	C	O					UNDEFINED CONCENTRATION
	MERCURY	L,G	T	F					QUANTITIES UNDEFINED
	CADIUM	G	T	F					QUANTITIES UNDEFINED
	TELLURIUM	P	PT	F					QUANTITIES UNDEFINED
	BERYLLIUM	P	T	F					QUANTITIES UNDEFINED
	COPPER	P	PT	F					QUANTITIES UNDEFINED
AUTOMATED CUTTING/POLISHING	OIL/WATER SOLUBLE	L,G	PF	F				760	UNDEFINED
	CUT/POLISH FLUIDS	L,G	PT,PF	I,F	0.003	0.003		760	UNDEFINED
	DISTILLED WATER	L,G		I	0.031	0.031		760	
	MERCURY	P,G	T	F				760	QUANTITIES UNDEFINED
	CADIUM	P,G	T	F				760	QUANTITIES UNDEFINED
	TELLURIUM	P	PT	F				760	QUANTITIES UNDEFINED
	COPPER	P	PT	F				760	QUANTITIES UNDEFINED
	AMPOULE FRAGMENTS	P	PT	I				760	
	BOULE FRAGMENTS	P	PT,PF	F				760	
	CLEANING FLUIDS							760	
	WATER	L,G		I				760	
	WEAK ACIDS	L,G	PT	I,O					UNDEFINED CONCENTRATION
	ENCAPSULANT MATERIAL	P	PF	F	0.0004	0.0004		760	
	ETCHING SOLUTIONS	L,G	T	O	2.592	2.592		760	LISTED IN FLUIDS GLOVEBOX
FOURIER TRANSFORM	NITROGEN	G		I				760	VENT TO MAINTAIN 1 ATM
INFRARED SPECTROMETER	NITROGEN	L	K	I	14.756			760	VENT TO MAINTAIN 1 ATM
	CONTAINED CONTAMINANTS	P,G	PT,PF	F				760	ELEMENTS LISTED IN SMALL BRIDGEMAN FACILITY
	AMPOULE BREAKAGE	P	PT	I					
	BOULE FRAGMENTS	P	PT,PF	F					

HAZARDS
T = TOXIC
F = FLAMMABLE
C = CORROSIVE
K = COLD
SC = SUPPORT COMBUSTION
PT = POSSIBLY TOXIC
PF = POSSIBLY FLAMMABLE

CONSTITUENT TYPE
A = ACID
B = BASE
O = OXIDIZER
F = FUEL
I = INERT

ORIGINAL PAGE IS OF POOR QUALITY

Table E-4 Droplet Burning Experiment

EXPERIMENT : DROPLET BURNING

PURPOSE : PRODUCES SINGLE DROPLETS OR A SPRAY OF LIQUID FUEL IN A VARIETY OF CATALYTIC AND BURN-SUPPRESSING MEDIA AND IGNITES THE FUEL SO OBSERVATIONS OF FLAME SPREADING, FLAME CONVECTION, AND DROPLET DISPERSAL CAN BE MADE

CYCLES: 10 PER 90 DAYS

EXPERIMENT FACILITIES	CONSTITUENTS IN FACILITY	PHASE	HAZARDS	CONSTITUENT TYPE	MASS VENTED PER CYCLE (LBM)	VOLUME VENTED PER CYCLE (CU IN.)	VENT RATE (CU.IN./MIN)	FINAL VENT PRESSURE (TORR)	COMMENTS
DROPLET/SPRAY BURNING FACILITY	WATER, DEIONIZED	L			0.000	0.001		760	USED FOR CLEANING
	NITROGEN	G		I	0.536	11899.633		0.001	EACH RUN CONTAINS 21/78 O2/H2 W/1 PART AR OR He
	OXYGEN	G		O	0.165	3203.747			
	HELIUM	G		I	0.001	152.559		0.001	EACH RUN CONTAINS 21/78 O2/H2 W/1 PART AR OR He
	ARGON	G		I	0.010	152.559		0.001	EACH RUN CONTAINS 21/78 O2/H2 W/1 PART AR OR He
	AIR	G		I,O	0.141	3051.188		0.001	USED TO REFILL FACILITY AFTER RUN
	TOLUENE	L,G	F,T		0.066	18.307		0.001	SUSPECTED CARCINGEN
	BURN CATALYTIC & SUPPRESSANT COMPOUNDS	L,G,P	C		0.000	0.006		0.001	
	CLEANING FLUIDS	L,G	PT		0.000	0.006		760	POSSIBLY FREON APPROX. 25 LITERS/90 DAYS
	COMBUSTION PRODUCTS	L,G,P	C, PT		0.740	14639.844		0.001	CORROSIVE
FLUIDS GLOVEBOX	NITROGEN	G		I	0.413	9153.564		760	MAY BE RECYCLED
	TOLUENE	L,G	F,T	F					
	CLEANING FLUIDS	L,G	PT						
	WATER	L							
GAS CHROMATAGRAPH	HELIUM	G		I	0.392	6102.376		0.01	TRACE VAPORS MAY BE IN N2
	ARGON	G		I	0.392	6102.376		0.01	
	LIQUID NITROGEN	L	K	I	1.774	61.024		0.01	FOR COLD TRAP
	AIR	G		I,O					
	ACETYLENE	G	PT,F	F	0.000	0.549		0.01	
	NITROGEN	G		I	0.392	6102.376		0.01	
HIGH PERFORMANCE LIQUID CHROMATOGRAPH	ACETONITRILE				0.011	0.305		760	USED WITH WATER IN VARYING AMOUNTS
	DISINFECTANTS				0.001	0.031		760	USED WITH METHANOL AND ACETONITRITE
	DISTILLED WATER				0.034	1.220		760	MOBILE PHASE IN VARYING AMOUNTS
	METHANOL			F					

HAZARDS
T - TOXIC
F - FLAMMABLE
C - CORROSIVE
PT - POSSIBLY TOXIC
PF - POSSIBLY FLAMMABLE
K - COLD

CONSTITUENT TYPE
O - OXIDIZER
F - FUEL
A - ACID
B - BASE
I - INERT

Table E-5 Electroepitaxy Crystal Growth Experiment

EXPERIMENT : ELECTROEPITAXY CRYSTAL GROWTH

PURPOSE : GROWS BULK QUANTITIES OF SINGLE CRYSTAL GALLIUM ARSENIDE BY ELECTROEPITAXY

CYCLES: 5 PER 90 DAYS

EXPERIMENT FACILITIES	CONSTITUENTS IN FACILITY	PHASE	HAZARDS	CONSTITUENT TYPE	MASS VENTED PER CYCLE (LBM)	VOLUME VENTED PER CYCLE (CU IN.)	FINAL VENT PRESSURE (TORR)	COMMENTS
ELECTROEPITAXY CRYSTAL GROWTH	AIR	G		I,O	0.006	122.048	0.001	USED TO REFILL FACILITY AFTER RUN
	HYDROGEN	G	T,F	F	0.099	30511.880	760	USED AS PURGE GAS
	GALLIUM	L,G,P	T	F				
	ARSENIC	P	T	F				
	GALLIUM ARSENIDE	P	T	F	0.000	0.000	760	
	COOLING FLUIDS	L,G						
	DISTILLED WATER	L			0.004	0.122		
	BOULE FRAGMENTS	L,G	PT					
	SEED CRYSTALS	P			0.000	0.000	760	
	NITROGEN	G		I	1.378	30511.880	760	USED TO PURGE SYSTEM PRIOR TO H2 PURGE
	POLISHING SOLUTIONS	L/G	PT,PF,C				760	
	SOURCE MATERIAL				0.024	0.122	760	INCLUDES POLYCRYSTALLINE SOURCE AND SEPARATED
								SPECIES
FLUIDS GLOVEBOX	GALLIUM	L,G,P	T	F				
	ARSENIC	G,P	T	F				
	GALLIUM ARSENIDE	P	T	F	0.000	0.000	760	SAMPLE CRYSTAL REMOVED FOR CUTTING & POLISHING
	NITROGEN	G		I	0.413	9153.564	760	EXPECT TO RECYCLE GN2
	ETCHANTS - HCL	L,G	PT	O				
AUTOMATED CUTTING/POLISHING	DISTILLED WATER	L			0.001	0.031	760	
	GALLIUM	L,G,P	T	F				THIS EXPERIMENT WILL RELEASE SAMPLE MATERIAL
	ARSENIC			F				INTO THE WORKING ENVIRONMENT
	GALLIUM ARSENIDE	P	T	F			760	
	CUTTING POLISH SOLUTION	L,G	PF,PT		0.000	0.003	760	
	ETCHING SOLUTION	L		O	0.094	0.323	760	
	ENCAPSULANT MATERIAL	P		F	0.000	0.000	760	
FOURIER TRANSFORM	NITROGEN	G		I			760	VENT TO MAINTAIN 1 ATM
INFRERED SPECTROMETER	LIQUID NITROGEN	L	K	I	0.533	18.307	760	VENT TO MAINTAIN 1 ATM
	AIR	G		I,O				
	GALLIUM	L,G,P	T	F				
	ARSENIC	G,P	T	F				
	GALLIUM ARSENIDE	P	T	F				

HAZARDS
T - TOXIC
F - FLAMMABLE
C - CORROSIVE
PT - POSSIBLY TOXIC
PF - POSSIBLY FLAMMABLE
K - COLD

CONSTITUENT TYPE
O - OXIDIZER
F - FUEL
A - ACID
B - BASE
I - INERT

Table E-6 Electromagnetic Levitator Experiment

EXPERIMENT : ELECTROMAGNETIC LEVITATOR

PURPOSE : ALLOWS A CONDUCTIVE SAMPLE TO BE POSITIONED IN THE LEVITATION COIL AND MELTED BY INDUCTIVE HEATING IN A VACUUM OR CONTROLLED GASEOUS ENVIRONMENT

CYCLES: 9 PER 90 DAYS

EXPERIMENT FACILITIES	CONSTITUENTS IN FACILITY	PHASE	HAZARDS	CONSTITUENT TYPE	MASS VENTED PER CYCLE (LBM)	VOLUME VENTED PER CYCLE (CU IN.)	VENT RATE (CU.IN./MIN)	FINAL VENT PRESSURE (TORR)	COMMENTS
ELECTROMAGNETIC LEVITATOR	HELIUM	G		I	0.009	1464.570		1E-07	COULD BE AR OR HE DEPENDING ON MATERIAL
	ARGON	G		I	0.094	1464.570		1E-07	EVACUATE TO 1E-9 TORR
	DISTILLED WATER	L			0.000	0.006		760	USED FOR FACILITY CLEAN-UP
	AIR	G		I,O	0.068	1464.570		0.000001	USED TO REFILL FACILITY AFTER RUN
	RAW MATERIALS	P	CONDUCTIVE					760	SAMPLE SIZES RANGE FROM MM TO 1.5 CM IN DIA.
	TUNGSTEN	P	CONDUCTIVE	F					
	TANTALUM	P	CONDUCTIVE	F					
	NICKEL ALLOYS	P	CONDUCTIVE	F					
	NIOBIUM	P	CONDUCTIVE	F					
	CLEANING FLUIDS	L,G			0.000	0.001		760	
	BOULE FRAGMENTS	L,P							
	MELT VAPORS	G	PT						
	PRODUCT FRAGMENTS	P							
	CUT/POLISH FLUIDS	L,G	PT,PF						
AUTOMATED CUTTING/POLISHING	DISTILLED WATER	L			0.001	0.031		760	DEVICE WILL RELEASE SAMPLE MATERIALS INTO ENVIRMT.
	RAW MATERIALS	P	CONDUCTIVE	F	0.000	0.000		760	
	CUT/POLISH SOLUTION	L			0.000	0.003		760	
	ENCAPSULANT MATERIAL	P	PT,PF	F	0.000	0.000		760	
SCANNING ELECTRON MICROSCOPE	LIQUID NITROGEN	L	K	I	3.547	122.048		0.000005	USED FOR COLD TRAP
	ARGON	G		I	0.111	1726.972		0.000001	EVACUATE TO 1E-6 AND BACKFILL WITH AR GAS TO 1E-4 TO 1E-3 TORR
FLUIDS GLOVEBOX	NITROGEN	G		I	0.413	9153.564		760	THIS MAY BE RECYCLED
	METAL POWDERS FROM RAW MATERIALS	P	CONDUCTIVE	F					
	ETCHANT SOLUTIONS	L,G	PT,PF		0.093	0.323		760	
	PLASTIC ENCAPSULATE	P	PT,PF	F					
	CLEANING FLUIDS	L,G	PT						

HAZARDS
T - TOXIC
F - FLAMMABLE
C - CORROSIVE
PT - POSSIBLY TOXIC
PF - POSSIBLY FLAMMABLE
K - COLD

CONSTITUENT TYPE
O - OXIDIZER
F - FUEL
A - ACID
B - BASE
I - INERT

Table E-7 Free Surface Phenomena Experiment

EXPERIMENT : Free Surface Phenomena

PURPOSE : Observes surface tension driven convection of a free liquid surface under a variety of temperature, pressure, and cover gas conditions

CYCLES: 9 PER 90 DAYS

EXPERIMENT FACILITIES	CONSTITUENTS IN FACILITY	PHASE	HAZARDS	CONSTITUENT TYPE	MASS VENTED PER CYCLE (LBM)	VOLUME VENTED PER CYCLE (CU IN.)	VENT RATE (CU.IN./MIN)	FINAL VENT PRESSURE (TORR)	COMMENTS
Fluid Physics Facility	Nitrogen	G		I	0.083	1830.713		760	Used for purging vent to maintain ATM in facility
	Water, Deionized	L			0.004	0.122		760	Used as the sample and to clean the facility
	Air	G		I,O					
	Cleaning Fluids	L,G	PT		0.000	0.006		760	May include a variety of solvents
	Raw Solution				0.004	0.061		760	
	CaF2	P	T, F						
	KPB	P	T,F						
	Seed Crystals	P	T, F						
	Solvents	L	F, PT						
	Spent TGS	L							
	TGS Solution	P	T						
	X-Ray Film Developer	L,G	T						
	X-Ray Film Fixer	L,G	PT						
Fluids Glove Box	Nitrogen	G		I	0.413	9153.564		760	May be recycled
Automated Cutting/Polishing	Product Fragments	P						760	
	Cutting/Polishing, Fluid	L,G						760	
	Cleaning Fluids	L,G	PT		0.000	0.003		760	
	Distilled Water	L			0.001	0.031		760	
Fourier Transform	Nitrogen	G		I		0.000		760	Vent to Maintain 1 ATM
Infrared	Liquid Nitrogen	L	K	I	0.533	18.307		760	Vent to Maintain 1 ATM
Spectrometer	Air	G		I,O					

HAZARDS	CONSTITUENT TYPE
T - TOXIC	O - OXIDIZER
F - FLAMMABLE	F - FUEL
C - CORROSIVE	A - ACID
PT - POSSIBLY TOXIC	B - BASE
PF - POSSIBLY FLAMMABLE	I - INERT
K - COLD	

Table E-8 Membrane Production Experiment

EXPERIMENT : Membrane Production Facility

PURPOSE : Prepares a series of Langmuir - Blodgett absorbed multilayer membrane films to study the effect of compositional and production Variables on Resulting Film Structures

CYCLES: 9 PER 90 DAYS

EXPERIMENT FACILITIES	CONSTITUENTS IN FACILITY	PHASE	HAZARDS	CONSTITUENT TYPE	MASS VENTED PER CYCLE (LBM)	VOLUME VENTED PER CYCLE (CU IN.)	VENT RATE (CU.IN./MIN)	FINAL VENT PRESSURE (TORR)	COMMENTS
Membrane Production Facility	Water Deionized	L			0.000	0.003		760	Used for Facility Cleanup
	Nitrogen	G		I					
	Air	G		I,O					
	Monomer/Polymer Compounds	L,G	PF, PT	F	0.000	0.000		760	
	Catalyst Solution	G	PF,PT		0.000	0.000		760	Oxidizers
	Cleaning Fluids	L,G	PT		0.001	0.015		760	
Fourier Transform Spectrometer	Nitrogen	G		I	0.000	0.000		760	Vent to maintain/ATM
	Air	G		I,O				760	Vent to maintain/ATM
	Liquid Nitrogen	L	K	I	0.532	18.307		760	Cold Trap Fluid
Scanning Electron Microscope	Liquid Nitrogen	L	K	I	3.547	122.048		0.000005	Per hour use for cold trap.
	Monomer Solution	L,G	PF, PT	F					
	Catalyst Solution	L,G	PF, PT						
	Cleaning Fluids	L,G	PT					760	
	Argon	G		I	0.111	1726.972		0.000001	Evacuate to 1E-6 and backfill with Argon to 1E-3 TORR
Sputtering Deposition Unit	Air	G		I,O					
	Argon	G		I					
	Trace Vapors	G	PF, PT		0.111	1726.972			
Fluids Glovebox	Nitrogen	G		I	0.413	9153.564		760	May be Recycled
	Monomer Solution	L,G	PF,PT	F					
	Catalyst Solution	L,G	PF,PT						
	Cleaning Fluids	L,G	PT						

HAZARDS
T - TOXIC
F - FLAMMABLE
C - CORROSIVE
PT - POSSIBLY TOXIC
PF - POSSIBLY FLAMMABLE
K - COLD

CONSTITUENT TYPE
O - OXIDIZER
F - FUEL
A - ACID
B - BASE
I - INERT

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Table E-9 Monodisperse Latex Spheres Experiment

EXPERIMENT : Monodisperse Latex Spheres

PURPOSE : Produces monodisperse latex spheres of specific size to meet customer specifications.

CYCLES: 9 PER 90 DAYS

EXPERIMENT FACILITIES	CONSTITUENTS IN FACILITY	PHASE	HAZARDS	CONSTITUENT TYPE	MASS VENTED PER CYCLE (LBM)	VOLUME VENTED PER CYCLE (CU IN.)	VENT RATE (CU.IN./MIN)	FINAL VENT PRESSURE (TORR)	COMMENTS
Latex Reactor System Facility	Latex Solution	L		F	0.000	0.006		760	
	Seed Spheres	P	T	F	0.000	0.005		760	Will require refrigeration
	Styrene		T,F	F					
	Initiator	L,P			0.000	0.002		760	Will depend on type selected
	AMBN Process								
	Product Spheres	P	F	F					
	Water	L							
	Reactors							760	Each reactor is 2 liters in volume
	Cleaning Fluids	L, G	F, PT						
Fluids Glovebox	Nitrogen	G		I	0.413	9153.564		760	This may be recycled
	Latex Solution	L		F					
	Seed Spheres	P	F	F					
	Styrene		T, F	F					
	Initiator	L, P							
	AMBN								
	Product Spheres	P	F	F					
	Water								
	Cleaning Fluids	L, G							
Scanning Electron. Microscope	Liquid Nitrogen	L	K	I	3.554	122.048		0.000005	Evacuate to .5E-5 TORR
	Argon	G		I	0.111	1726.972		0.000001	Evacuate to 1E-6 TORR and backfill with argon gas to 1E-3 TORR.

HAZARDS
T - TOXIC
F - FLAMMABLE
C - CORROSIVE
PT - POSSIBLY TOXIC
PF - POSSIBLY FLAMMABLE
K - COLD

CONSTITUENT TYPE
O - OXIDIZER
F - FUEL
A - ACID
B - BASE
I - INERT

Table E-10 Protein Crystal Growth Experiment

EXPERIMENT : PROTEIN CRYSTAL GROWTH

PURPOSE : GROWS PROTEIN CRYSTALS FROM PREPARED SATURATED SOLUTION TO PERFORM X-RAY DIFFRACTION ANALYSIS OF SELECTED PROTEINS AND TRANSMIT DIFFRACTION DATA TO THE GROUND

CYCLES: 7 PER 90 DAYS

EXPERIMENT FACILITIES	CONSTITUENTS IN FACILITY	PHASE	CONTITUENT TYPE	HAZARDS	MASS VENTED PER CYCLE (LBM)	VOLUME VENTED PER CYCLE (CU IN.)	VENT RATE (CU.IN./MIN)	FINAL VENT PRESSURE (TORR)	COMMENTS
PROTEIN CRYSTAL GROWTH	SEED CRYSTALS	P	F	T					
	WATER/ DEIONIZE/DEPYROG	L						760	
	DISINFECTANTS	L,G		T	0.002	0.043		760	USED TO MIX WITH RESERVOIR AND PROTEIN SOLUTION
	NITROGEN	G	I		0.000	0.001		760	
	OXYGEN	G	O		0.992	21968.554		620	
	HYDROGEN	G	F		0.113	2196.855		620	
	ARGON	G	I						
	AIR	G	I,O,F		0.141	2196.855		620	MUST HAVE AT LEAST 360 LITERS ON BOARD
	CLEANING FLUIDS	L,G		PT					
	RAW PROTEIN SOLUTION	L	F		0.000	0.012		760	SHIPPED SEPARATELY OR IN SYRINGES
	PROTEIN	P	F						
	SOLVENTS	L,G							
	ACETONITRILE	L,G							
	ETHANOL	L,G	F						
	ACETONE	L,G	F						
	MPD	L,G							
	DIMETHYL SULFONIDE	L,G							
	DIMETHYL FORMAMIDE	L,G	F						
	SALT SOLUTIONS	L			0.001	0.009		760	MIXED WITH WATER GIVEN IN CONSUMABLE TABLE
	NaCl	L	I						
	MgSO4	L	I						
	(NH4)2SO4	L							
	Na3Citrate	L							
	Na2SO4	L							
	K2SO4	L							
	Na3C45O7	L							
	KH2PO4 & K2HPO4	L							
FLUIDS GLOVEBOX	NITROGEN	G	I		0.413	9153.564		760	MAY BE RECYCLES
	CLEANING FLUIDS	L,G		PT					
	RAW PROTEIN SOLUTION	L	F						
	SALT SOLUTIONS	L							
	COOLING FLUIDS	L							
	DISINFECTANTS	L,G		T					

HAZARDS
T - TOXIC
F - FLAMMABLE
C - CORROSIVE
PT - POSSIBLY TOXIC
PF - POSSIBLY FLAMMABLE
K - COLD

CONSTITUENT TYPE
O - OXIDIZER
F - FUEL
A - ACID
B - BASE
I - INERT

Table E-11 Solidification of Immiscible Alloys Experiment

EXPERIMENT : Solidification of Immiscible Alloys

PURPOSE : Melts and resolidifies a dispersion of immiscible materials such as aluminum and indium under isothermal conditions.

CYCLES: 9 PER 90 DAYS

EXPERIMENT FACILITIES	CONSTITUENTS IN FACILITY	PHASE	HAZARDS	CONSTITUENT TYPE	MASS VENTED PER CYCLE (LBM)	VOLUME VENTED PER CYCLE (CU IN)	VENT RATE (CU.IN./MIN)	FINAL VENT PRESSURE (TORR)	COMMENTS
Alloy Solidification Facility	Plastic Encapsulate	L,G	F	F					
	Water, Distilled	L			17.637	0.488		760	Used for facility clean-up
	Argon	G		I	1929.044	42716.632		0.001	Gases may include either Ar, N2 or He
	Metal Powders	P	PT	F				760	May include traces of sample elements
	Berrylium	P		F					
	Copper	P		F					
	Aluminum	P		F					
	Indium	P		F					
	Carbon Steel	P		F					
	Iron	P		F					
	Nickel	P		F					
	Melt Vapors	G		F					
	Cleaning Fluids	L,G	PT		132.277	3.661		760	
	GHe	G		I	1.565	244.095		0.001	Used for Sample Quench
	Air	G		I,O,F	1975.341	42716.632		0.001	used to refill facility after run
Fluids Glovebox	Nitrogen	G		I					
	Metal Powders	P		F					
	Berylium	P		F					
	Copper	P		F					
	Aluminum	P		F					
	Indium	P		F					
	Carbon Steel	P		F					
	Iron	P		F					
	Nickel	P		F					
	Etchant Solutions	L,G	PT		93.630			760	
	Plastic Encapsule	L,G,P	PF	F	0.014			760	
	Cleaning Fluids	L,G	PT						
Automated Cutting /Polishing									
	Water Distilled	L			1.102	0.031		760	
	Metal Powders	P	PT, PF	F				760	This device will release sample material into the working environment
	Berylium	P		F					
	Copper	P		F					
	Aluminum	P		F					
	Indium	P		F					
	Carbon Steel	P		F					
	Iron	P		F					
	Nickel	P		F					
	Plastic, Encapsulate	L, P		F					
	Cleaning Fluids	L,G							
	Electropolishing L/P	L,P	PT, PF						
	Solution	L,G			0.110	0.003		760	
Scanning Electron Microscope	Liquid Nitrogen	L	K	I	3553.851	122.048		0.000005	Evacuate to .5E-5 TORR
	Argon	G		I	111.047	1726.972		0.000001	Evacuate to 1E-6 and back fill with Argon to 1E-4 to 1E-3 TORR

HAZARDS
T = TOXIC
F = FLAMMABLE
C = CORROSIVE
PT = POSSIBLY TOXIC
PF = POSSIBLY FLAMMABLE
K = COLD

CONSTITUENT TYPE
O = OXIDIZER
F = FUEL
A = ACID
B = BASE
I = INERT

Table E-12 Solid Surface Burning Experiment

EXPERIMENT : Solid Surface Burning

PURPOSE : Studies the spreading of open flames along a material surface in the presence of concurrent and countercurrent flows of controlled composition atmosphere in microgravity

CYCLES: 10 PER 90 DAYS

EXPERIMENT FACILITIES	CONSTITUENTS IN FACILITY	PHASE	HAZARDS	CONSTITUENT TYPE	MASS VENTED PER CYCLE (LBM)	VOLUME VENTED PER CYCLE (CU IN.)	VENT RATE (CU.IN./MIN)	FINAL VENT PRESSURE (TORR)	COMMENTS
Solid Surface Burning Facility	Water Deionized	L			0.00004	0.001		760	Wash after 5 runs. Amounts given on per run basis.
	Nitrogen	G		I	0.53738	11899.633		0.001	Combinations of 21/78 O2/N2 part Ar or He totaling
	Oxygen	G	F,T	O	0.16552	3185.440		0.001	250 liters
	Helium	G		I	0.00099	152.559		0.001	See GO2 & GN2
	Argon	G		I	0.00981	152.559		0.001	See GO2 & GN2
	Air	G		I,O	0.14110	3051.188		0.001	Used to refill facility after run
	Freon	G	PT		0.00004	0.001		760	Used for cleaning
	Raw Materials	P	F	F	0.05512	3.051		760	Could be organic or inorganic fuels
	Coal	P	F	F					
	Paper	P	F	F					
	PMMA	P	F	F					
	Wood	P	F	F					
	Felts	P	F	F					
	Plastics	P	F	F					
	Magnesium	P	F	F					
	Potasium	P	F	F					
	Lithium	P	F	F					
	Combustion Products	L,G,P	F		0.73037	14623.612		0.001	Varies depending on completeness of burn
	Carbon Dioxide	G							
	Water	L,G							
	Carbon Monoxide	G	T	F					
	Ash	P		F					
	Soot	P		F					
	Tar	P		F					
Gas									
Chromatograph	Nitrogen	G		I	0.27558	6102.376		0.01	Required with He & Ar as carrier gases
	Helium	G		I	0.39242	6102.376		0.01	Required with N2 and Ar as carrier gases.
	Argon	G		I	0.39242	6102.376		0.01	Required with N2 and He as carrier gases.
	Liquid Nitrogen	L	K	I	1.77693	61.024		0.01	for cold trap.
	Air	G		I,O,F	0.14110	3051.188		0.01	Used to refill the facility after run.
	Acetylene	G	T,F	F	0.00000	0.006		0.01	These gases will contain amounts of the sample material.

HAZARDS
T - TOXIC
F - FLAMMABLE
C - CORROSIVE
PT - POSSIBLY TOXIC
PF - POSSIBLY FLAMMABLE
K - COLD

CONSTITUENT TYPE
O - OXIDIZER
F - FUEL
A - ACID
B - BASE
I - INERT

Table E-13 Solution Crystal Growth Experiment

EXPERIMENT : Solution Crystal Growth

PURPOSE : Grows single crystal triglycine sulfate solution using a cooled seed crystal

CYCLES: 8 PER 90 DAYS

EXPERIMENT FACILITIES	CONSTITUENTS IN FACILITY	PHASE	HAZARDS	CONSTITUENT TYPE	MASS VENTED PER CYCLE (LBM)	VOLUME VENTED PER CYCLE (CU IN.)	VENT RATE (CU.IN./MIN)	FINAL VENT PRESSURE (TORR)	COMMENTS
Solution Crystal Growth	Solvents	L,G	F, PT		0.001	0.015		760	
Facility	Water, Deionized	L			0.004	0.122		760	
	Air	G		I,O					
	Nitrogen	G		I	0.995	22029.577		760	Used for purging
	Triglycene Sulfate Sol	L			0.011	0.183		760	Spent Solution will enter the waste disposal system
	Seed Crystals	P						760	Becomes the product crystals
	Cleaning Fluids	L,G	PT						
	Product Crystals	P						760	
	CaF2: KPB	P	T,F						
	Zeolites	P	T	I					Sodium Aluminate,Sodium Chlorate and Sodium Hydroxide
									are consumed when used for zeolite production
Fluids Glovebox	Nitrogen	G			0.413	9153.564		760	Maybe recycled
	Triglycene Sulfate Sol.	L							
	Seed Crystals	P							
	Cleaning Fluids	L,G	PT						
	Product Crystals	P							
Automated Cutting/Polishing	Water, Distilled	L			0.001	0.031		760	This device will release sample material into the working
	Triglycene Sulfate Sol.	L							environment.
	Seed Crystals	P							
	Cleaning Fluids	L,G	PT						
	Product Crystals	P							
	Sodium Aluminate	P							
	Sodium Chlorate	P		O					
	Sodium Hydroxide	L, P							
	Solvents (mostly organic)	L,G						760	
	Polishing Solution	PT, PF			0.000	0.003		760	
	Encapsulant Material	PF		F	0.000	0.000		760	
Fourier Transform	Nitrogen	G		I				760	Vent to maintain 1 atmosphere
Infrared	Product Crystals	P							
Spectrometer	Air	G		I,O,F		0.000			
	Liquid Nitrogen	L	K	I	0.533	18.307		760	Vent to maintain 1 atmosphere
	Cleaning Fluids	L,G	PT						

HAZARDS
T - TOXIC
F - FLAMMABLE
C - CORROSIVE
PT - POSSIBLY TOXIC
PF - POSSIBLY FLAMMABLE
K - COLD

CONSTITUENT TYPE
O - OXIDIZER
F - FUEL
A - ACID
B - BASE
I - INERT

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OF POOR QUALITY

Table E-14 Vapor Phase Crystal Growth Experiment

EXPERIMENT : VAPOR PHASE CRYSTAL GROWTH

PURPOSE : GROWS BULK QUANTITIES OF SINGLE CRYSTAL MERCURIC OXIDE BY CHEMICAL VAPOR TRANSPORT AND MONITORS PROCESS CONTROL PARAMETERS, INCLUDING VAPOR PRESSURE AND GROWTH RATE

CYCLES: 3 PER 90 DAYS

EXPERIMENT FACILITIES	CONSTITUENT VENTED	PHASE	HAZARDS	CONSTITUENT TYPE	MASS VENTED PER CYCLE (LBM)	VOLUME VENTED PER CYCLE (CU. IN.)	VENT RATE (CU.IN./MIN)	FINAL VENT PRESSURE (TORR)	COMMENTS
VAPOR CRYSTAL GROWTH FACILITY	ARGON	G		I	0.314	4881.901		0.001	USED FOR PURGING GROWTH MODULE
	AIR	G		I,O,F	0.635	13669.322		0.001	REFILL FURNACE CHAMBER AFTER RUN
	WEAK SOLUTIONS OF THE	L,G	PT,PF						
	FOLLOWING REAGENTS:		CORROSIVE						
	HYDROGEN PEROXIDE	L,G		O					
	HYDROFLUORIC ACIE	L,G		O					
	METHANOL	L,G		F					
	NITRIC ACID	L,G		O					
	HYDROCHLORIC ACID	L,G		O					
	SAMPLE MATERIALS	G,P		F	0.025	0.087		760	SEMICONDUCTOR ORGANIC COMPOUNDS
	MgCdTe	G,P		F				760	
	GaAs	G,P		F				760	
	InP	G,P		F				760	
	ZnTe	G,P		F				760	
	CdSe	G,P		F				760	
	GaP	G,P		F				760	
	Co	G,P		F				760	
	Ni	G,P		F				760	
	TRANSPORT GASES	G	T,REACTIVE		2.646	1952.760		0.001	
	MGBr2 I2	G	T,REACTIVE					0.001	
	MgCl2 MgI2 MgI	G	T,REACTIVE					0.001	
	TRACE GASES	G						0.001	
	ZnCl2 Water	G						0.001	
	Hcl HI Cl2	G						0.001	
	Hg	G,P							
	AMPOULE FRAGMENTS	P		I					
	BOULE FRAGMENTS	P	PT	F					
	CLEANING FLUIDS	L,G			0.000	0.006		760	WILL CONTAIN REACTIVE SOLUTIONS OF ACIDS AND BASES
	DISTILLED WATER	L			0.002	0.061		760	MIXED WITH CLEANING SOLUTION FOR CLEAN-UP
	POLISHING SOLUTIONS	L,G	PF,PT						
FLUIDS GLOVEBOX	NITROGEN	G		I	0.413	9153.564		760	MAY BE RECYCLES
	SAMPLE MATERIALS	G,P		F					
	MgCdTe	G,P		F					
	GaAs			F					
	InP			F					
	ZnTe			F					
	CdSe			F					
	GaP			F					
	Co			F					
	Ni			F					
	AMPOULE FRAGMENTS	G,P		I					
	BOULE FRAGMENTS	P	PT	F					
	CLEANING FLUIDS	L,G							

HAZARDS
T = TOXIC
F = FLAMMABLE
C = CORROSIVE
PT = POSSIBLY TOXIC
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K = COLD

CONSTITUENT TYPE
O = OXIDIZER
F = FUEL
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